LAFAYETTE COLLEGE

Department of Mechanical Engineering

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

Wheelchair Hill Assist Design Report

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Abstract

The wheelchair team has decided to focus on the issue of how wheelchairs ascend and descend ramps of varying grades. 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 drawbacks that may deter users including cost and portability. Although there are some products that allow the user to ascend or descend inclines currently on the market, a vast majority of them experienced challenges using these attachments, including portability, cost, and inefficient installation and removal. With these issues in mind, the product discussed in the report focuses on the issues cost, weight, accessibility, safety, portability and efficiency of the installation and removal process.

The main concept for the final product is to create a device that will 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. Various designs were created by the group, all of which are showcased throughout the report. Through research and consultation with wheelchair users and healthcare providers conducted through interviews and surveys, specifications and constraints have been created that will inform the design process later during prototyping and determine what the final design will be.

The group has split into three sub-teams in order to spread the work out evenly. The propulsion team is in charge of the motor and getting the wheelchair to move. The electro-mechanical integration (EMI) team is in charge of the user interface and circuitry. The effort sensing team is in charge of measuring the user input and motor output.

In terms of the budget, the device should cost no more than $2,500 as this is competitive with or below the current costs of existing products within the market. The group is currently on track with plans to complete all preliminary CAD designs by the end of the interim break, and have a fully functional prototype by the end of the school year.

1. 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 by creating a device designed to assist manual wheelchair users in ascending and descending inclines and declines. The focus of this project is to assist people who use wheelchairs or are considering using a wheelchair and allow accessibility to a greater number of locations. Additionally, we believe that people should not be limited in their accessibility based on their ability, or socio-economic status.

2. Motivation For Project

As of 2015, there were 2.7 million wheelchair users in the US [1], and according to the CDC, 13.7% of US adults have some form of disability relating to their mobility [2]. 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.

Improvements to wheelchairs is a broad category, but reaching a wide audience was a priority. To reach a wide audience, the project would benefit from being designed as a device that could be acquired and installed at a relatively low cost, weight, and could be attached to an existing wheelchair. Wheelchair users face a variety of issues, but this project must have a more specific focus. 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 [3]. 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 [4]. 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 [5]. For example, Table A.1 (Appendix A) emphasizes the accessibility issues associated with restrooms or narrow aisles [3] and ultimately any add-ons for this project should not worsen the accessibility of a manual wheelchair. With the research presented above, there were two main interests: steep inclines and declines and stair climbing. The 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 wheelchair. With the focus solidified, a strong understanding of the audience is still required.

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 wheelchair [6]. 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 manual wheelchair that is 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. This device 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 successful, this new system still needs to be made available to the public. An attempt could be made to file a patent and sell production rights, which if possible could be beneficial for the team, but may limit the market of consumers. The work could also be made open source, which 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. 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.

3. Societal and Technological Context of Design

A successful design effort will have implications in the larger societal and technological context. First, the design will impact the health, welfare, and safety of manual wheelchair users. Safety is a top priority for the device. This device will provide a safe alternative to manual and motorized wheelchair usage and is a major factor in design considerations. Also, in terms of the overall welfare of users, the device will provide increased accessibility and maneuverability for wheelchair users allowing them to overcome barriers created by inaccessibility or challenges when ascending or descending inclines in a wheelchair. The health of stakeholders and wheelchair users is also impacted by the increased ability for people who use wheelchairs to participate and engage in activities requiring ascending or descending inclines or declines, respectively. This medical device positively impacts the health of users because it allows for users to engage their bodies physically depending on the effort setting they have requested from the device. Similarly, increased accessibility and ability to engage as a person who uses wheelchairs has positive social implications for users. Eliminating or mitigating challenges associated with traversing inclines and declines for a person who uses wheelchairs helps remove social barriers created by accessibility challenges. Lastly, economically this device will provide an affordable alternative to current wheelchair add-ons. This will provide an opportunity for greater access to the product and the assistance it provides.

4. Description of Current State of the Art

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 wheelchair; therefore, wheelchair attachments try to mitigate the major drawbacks 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" [5]. 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 in 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 provided motivation for the team to provide a lightweight, low cost, accessible, safe, and easily transportable add-on device for a wheelchair to assist a person to ascend inclines and descend declines and helping to improve their quality of life. The assistive technology or add-ons currently available for wheelchair users traversing slopes fall into three main categories: push rim-activated power-assist wheels (Figure 1), wheelchair power drives (Figure 2), and mechanical advantage devices (Figure 3) [8].

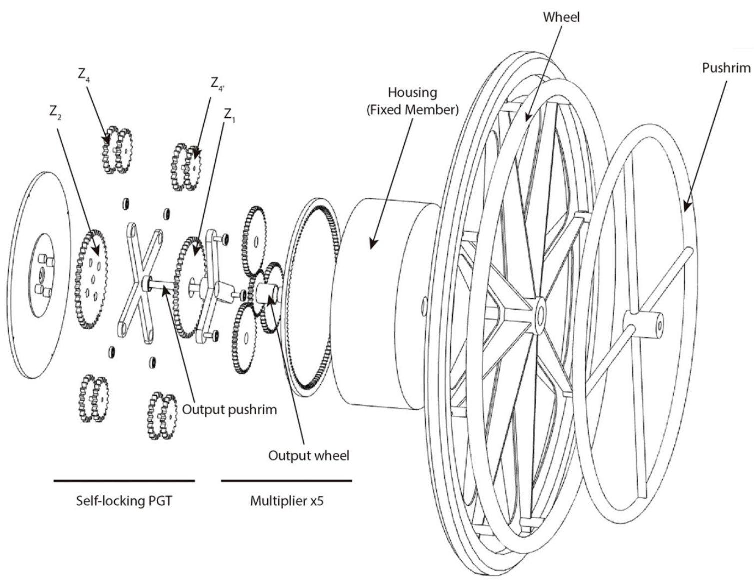


Figure 1 Pushrim-activated Power Assist Wheels (PAWAW) [9]

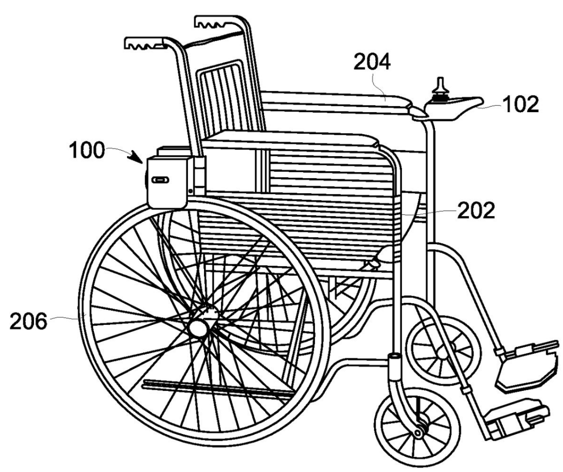


Figure 2 Wheelchair Power Drives [10]

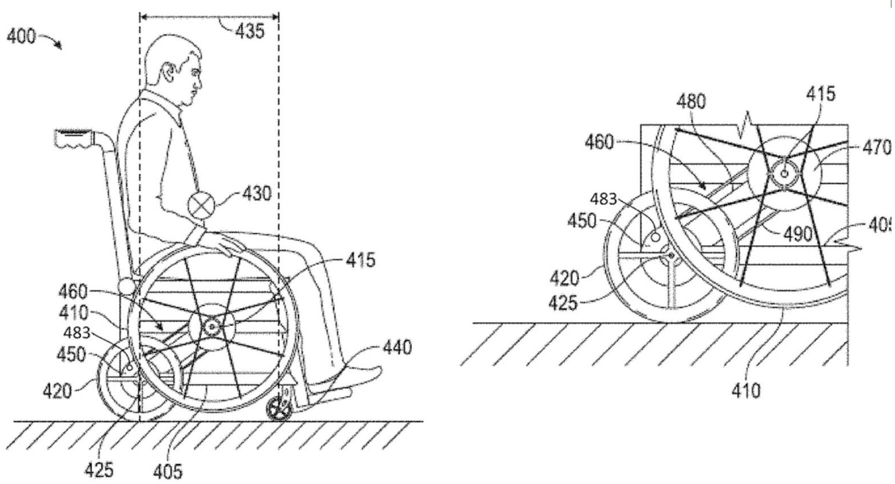


Figure 3 Mechanical Advantage Add-on [11]

Pushrim-activated power-assist wheels (PAWAW) is a manual wheelchair to which motorized wheels are added to provide power and aid with mobility [12]. 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 backward with one push than with a generic 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 [12].

Wheelchair power drives 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. 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 [8].

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 and motors. This propulsion device uses 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 [8].

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 [10]. 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 [10]. 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.

Taking a look into the current motor assist devices on the market the below table (Table 1) shows four products currently easily available. The four devices, the SmartDrive MX2 Power Assist [21], Firefly 2.5 [19], E-Motion [20] and SMOOV One [22] are broken down into their prices, added weight, maximum supported weight, range on full battery, and maximum speed. The Smart Drive MX2 Power Assist attaches to the back of the wheelchair and has a single wheel to propel the wheelchair [21]. Similarly, the SMOOV One attaches to the back of the wheelchair with a single wheel and motor in a slightly different configuration [22]. Conversely, Firefly 2.5 attaches to the front of the manual wheelchair and has a similar steering to an electric scooter or motorbike [19]. The E-Motion replaces the wheels of a manual wheelchair and uses hub motors and other technologies to assist in propulsion. These different values heavily influenced the metrics and constraints of the device, as shown below in the associated section (Section 5.1), consequently affecting design choices and considerations.

Table 1: Pricing, Weights, Range and Speeds of Different Wheelchair Add-On Devices currently on the market

	SmartDrive MX2 Power Assist [21]	**Firefly 2.5 [19]**	**E-Motion [20]**	**SMOOV One [22]**
Price (USD)	$6,317.90	$2,595.00	$2,595.00	$6,895+
Added Weight (lbs)	13.5	35 (shipping weight)	22	16
Maximum Supported Weight (lbs)	331	~	286	310
Range on full battery (miles)	12	15	15.53	12
Maximum Speed (mph)	5.5 (flat ground) 5.3 (6% degree incline)	12	3.73	6

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 [13]. 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 [8]. Just to traverse inclines or declines requires a significant amount of upper body strength and endurance [8]. Especially over a longer period of time, using a wheelchair can contribute to upper-body injuries including chronic shoulder pain [8]. 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 easily transportable product [8].

5. Planned Approach

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 goal of the attachment is to allow wheelchair users to gain independence and struggle less when ascending and descending steep slopes. Specific design objectives have been generated that will assist in achieving this overall goal. The most important functions of the device are to measure the effort/input of the wheelchair user, apply both positive and negative torque, control the direction of the wheelchair, and allow for folding/interfacing with common wheelchairs. Table 2 is a morphology chart that lists various options of how these important functions can be achieved.

Table 2: 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 in order to control 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 utilizing 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 a knob to enable the user to control the speed of assistance outputted from the device. Additionally, there will be a joystick to enable the user to control the direction of the wheelchair.

Conceptual designs,which were generated by individual members of the team, were created by considering the design objectives (Appendix B). 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 considering 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 the attachment on the wheelchair. The importance of this feature will be determined through survey and interview feedback the team obtains. Designs also came from researching the prior art. This large compilation of ideas has allowed the team to narrow the scope and 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 subsystems: the motors and transmission, the controls, and effort sensing. The subsystems will be integrated, but designed separately due to the fact there is a weak coupling between the different subsystems. The major subsystem identified is the motor and transmission, so the team further considered how they could achieve this subsystem. These considerations can be found in Table 3.

Table 3: Drivetrain function/means and other considerations (Transmit positive/negative torque)

Motor Types	Transmission	Apply Negative Torque
• Brushed DC • Brushless DC Motors • No motor (ratcheting mechanism)	• Hub Motor • Belt Drive • Direct Wheel to Motor Interfaces • Differential • Pinching the wheels with driven wheels (Friction Drive) • Gears/Gearbox	• Resistive loading • Running motor backward • Variable Rotary damper (passive?) • Bike brakes

Planned Approach - Design Metrics and Constraints

The specifications identified are derived from the design objectives, which have been informed by research on the largest areas of improvement for wheelchair users. Various engineering metrics will inform the specifications, which are found in Table 4. Initially, general specifications, functions, and constraints were developed, but as subteam work has developed, subteam specific metrics emerged. Some measurable quantities identified are the velocity, acceleration, weight of the device components, weight the device and wheelchair can support, cost, and maximum incline grade the wheelchair is designed to climb. Metrics that stem from this involve maximum and unassisted achievable velocity on level ground and specified incline or decline (Specifications 6, 7-12). The unassisted achievable velocity is the lower bound of the maximum speed achievable by the device and controller with no user input for acceleration or deceleration. The range of maximum grade was derived from the range that most electric wheelchairs are rated to maneuver [14]. Maximum and unassisted achievable velocities were based on The International Organization for Standardization (ISO) standards of the maximum velocity of electric wheelchairs and the average speed of manual wheelchairs (ISO 7176) [15, 16]. Another metric includes waterproofing the housing to ensure the device will be operable in different weather phenomena (Specification 5). All specifications are given in Table 4. Testing for waterproofing of components will take direction from ISO 7176-9, which describes climatic testing of electric wheelchairs [15]. 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 that the wheelchair is rated to carry, which can be seen in Table 1 [17]. These complement design objectives stated above and are seen in conceptual drawings (Appendix B). Subsystem specifications will be further developed as prototyping and modeling continue.

Table 4: 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 1)	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 1) [17]	Added weight of the device		25	lbs.
3	The range of the device on a full battery with 0% effort from user is comparable with the average distance traveled by a person in a day	Range of device on full battery with no user effort	1.5	2	Miles
4	The range of the device on a full battery with 50% effort from user is comparable and competitive to other prior art (Table 1)	Range of device on full battery with 50% user effort	12	15	Miles
5	The device can withstand weather including snow, and rain based on ISO 7176-9 [15]	Waterproofing housing for electrical components			
6	The device can operate at specified grade [14]	Maximum grade	8.3	12.5	% grade
7	The device can carry a person of 198 lbs at a maximum speed on level ground [15]	Maximum speed attainable on level ground		9.32	mph
8	The device can carry a person of 198 lbs at an unassisted achievable speed on level ground [18]	Unassisted achievable speed attainable on level ground	3		mph

Table 4: Design Specifications and Metrics Continued

#	Description	Metric/Specification	Minimum Value	Maximum Value	Unit
9	The device can carry a person of 198 lbs. at a maximum speed on an 8.3%-12.5% grade incline [15]	Maximum speed attainable on an incline		9.32	mph
10	The device can carry a person of 198 lbs. at an unassisted achievable speed on an 8.3%-12.5% grade incline [16]	Unassisted achievable speed attainable on an incline	2.25		mph
11	The device can carry a person of 198 lbs. at a maximum speed on an 8.3%-12.5% grade decline [15]	Maximum speed attainable on a decline		9.32	mph
12	The device can carry a person of 198 lbs. at an unassisted achievable speed on an 8.3%-12.5% grade decline [18]	Unassisted achievable speed attainable on a decline	3		mph

Considerable justification goes into each specification value. Specification 1 involves the maximum cost of the device. The maximum cost of the device will not exceed $2,500 (USD). This will put the device in the same price range as the Firefly 2.5 [19] and E-Motion [20] and significantly below the SmartDrive MX2 Power Assist [21], and the SMOOV One [22], all of which are existing motor assist devices on the market (Table 1). Similarly, Specification 2 was determined by putting the maximum added weight of the device components within the range of other motor assist devices currently on the market. As seen in Table 1, the range of added weight of the four prior art is 13.5 lbs - 35 lbs. 25 lbs is currently the specified added weight as it is in the middle of the prior art range (Specification 2). Specification 3 is based on the average distance an American walks in a day [23]. An average American walks around 1.5 to 2 miles per day [23]. This distance was used to determine the distance the battery of the device should be able to accomplish with no user effort (Specification 3). To ensure that the device is competitive with other motor assist devices on the market, the range of the battery should also be able to achieve a range of 12-15 miles at 50% user effort (Specification 4). The device needs to be able to withstand different weather phenomena such as snow and rain to allow the greatest accessibility and utility of the device. The International Organization for Standardization (ISO) has a standard ISO 7176-9 which specified the requirements and test methods to determine the effects of different climatic events for electric wheelchairs [15]. Standard ISO 7176-9 will be used to test the device and assess the device's ability to withstand different weather changes (Specification 5). Specification 6 was based on the maximum grade electric wheelchairs are rated to maneuver on 8.3% to 12.5% grade [14]. Specification 8-12 used the average weight of an American man (198 lbs) as the weight of the user for each specification [24]. The maximum speed for the device on level ground, a 8.3% -12.5% grade incline, and a 8.3% -12.5% grade decline is set at 9.32 mph (Specification 7, 9 & 11). While it is unlikely that the device will reach this speed especially on an incline or level ground, this speed is set by the International Organization for Standardization (ISO) as the maximum speed for electric wheelchairs according to ISO 7176-6 [15]. The unassisted achievable speed speed of the device on level ground (Specification 8) was determined by using the average walking speed of an adult [18]. This is used to ensure the user is at a safe speed, but not too slow to keep pace with additional foot traffic. This same unassisted achievable speed was used for the maximum grade decline (Specification 11) to keep the user within the same safe operating level but this speed can be increased or decreased based on the user's comfort. The unassisted achievable speed of the device on an incline was set at 2.25 mph (Specification 9), which was based on the average speed of a person who uses a manual wheelchair. While this is slower than the unassisted achievable speed for the flat ground and a decline, this is an achievable speed that would allow a wheelchair user to safely navigate an incline.

The design has additional constraints that have been developed through research and discussion. For example, the constraints of this design stem from ADA regulations [4] and ISO standards [15], which provide American and international standards for wheelchair design, which are seen as appropriate standards to follow. The ISO in particular is highly regarded as having appropriate constraints and standards across various fields [15]. Table 5 shows the constraints developed from the ISO regarding 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 allowable weight of the wheelchair used for prototyping and similar wheelchairs (Constraint 3) [17]. The electrical components have specific constraints that inform the design, which includes keeping the heat transfer of electrical components at a safe operating level (Constraint 5) [25]. 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) [26].

Table 5: Device Constraints

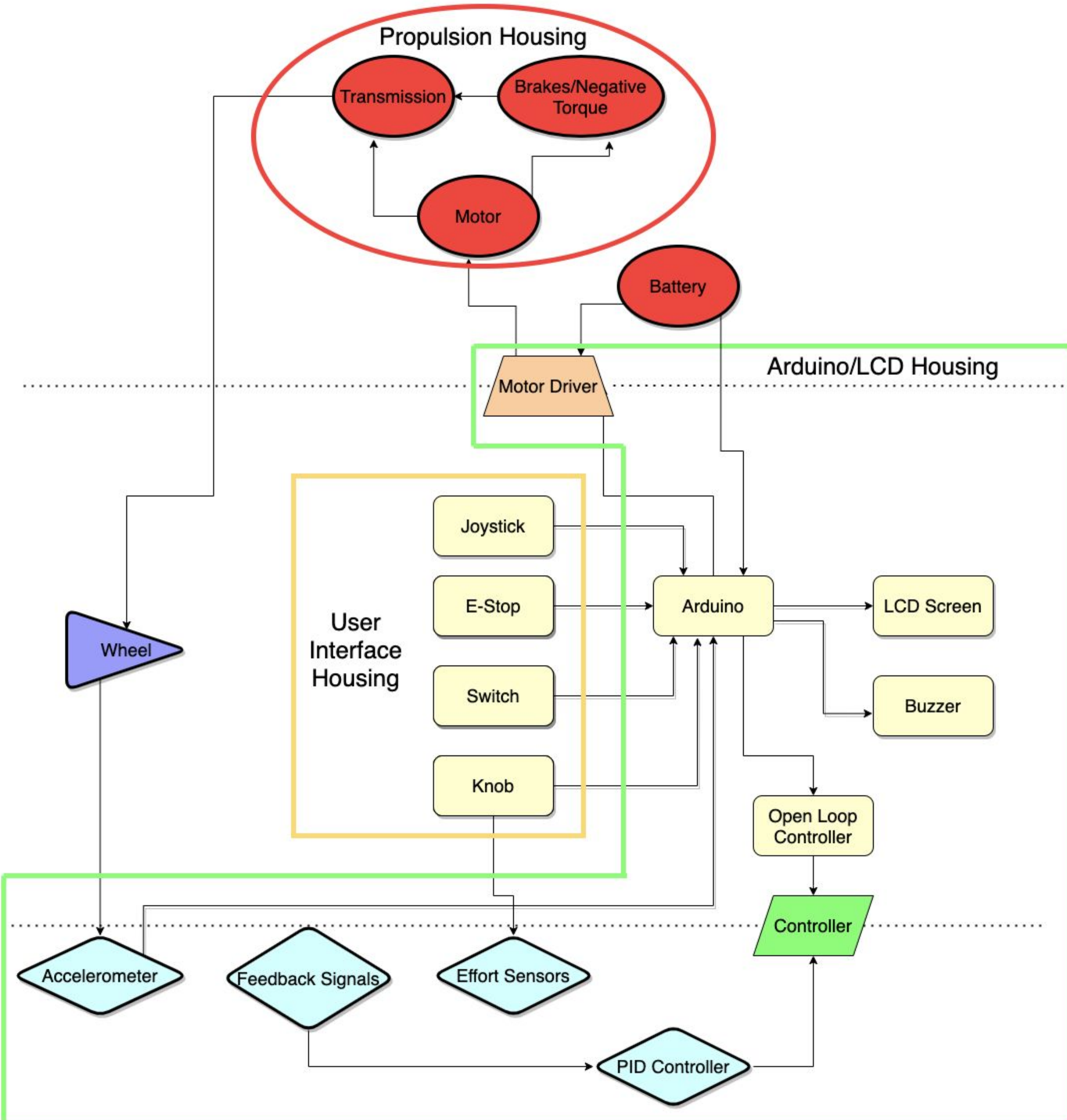
#	Description	Constraint	Max Value	Unit
1	The added width of the device does not exceed the specified length to allow the device and wheelchair to pass through an ADA regulated doorway [4]	Maximum added width	4	in.
2	The device does not exceed the maximum speed of electric wheelchairs standard set up by ISO 7176-6 [15]	Maximum speed of electric wheelchair	9.32	mph
3	The device must be designed such that it can support up to 300 lbs [17]	Maximum weight	300	lbs.
4	Emergency-stop of the device is an approved as an emergency-stop for commercial use [26]	Use of emergency-stop in commercial devices		
5	The device must be designed such that it does not exceed 158 °F [25]	Device temperature range	158	°F
6	The wheelchair design does not violate ISO 7176-1 establishing static stability testing of the chair [15]	Static stability		
7	The wheelchair design does not violate ISO 7176-2 establishing the dynamic stability of electrically powered wheelchairs [15]	Dynamic stability		
8	The wheelchair design does not violate ISO 7176-3 establishing the effectiveness of brakes [15]	Brake Effectiveness		
9	The wheelchair design does not violate the ISO 7176-10 determining the obstacle-climbing ability of electrically powered wheelchairs [15]	Obstacle climbing ability		
10	The wheelchair design does not violate the ISO 7176-14 requirements for power and control systems [15]	Power and control systems		
11	The wheelchair design does not violate the ISO 7176-25 requirements for batteries and chargers [15]	Batteries and charges		

The constraint values are also justified through evidence. Constraint 1 is derived from the width of the standard manual wheelchair (26 inches) and the standard width of a doorway (36 inches) [4]. Adding a width of 4 inches at maximum (Constraint 1) would make the width of the wheelchair and device 30 inches, which would still allow a wheelchair user enough space to pass through a standard doorway easily. Any added width limits the accessibility of the device. Many of the other constraints were set by the ISO's standards for wheelchairs to ensure the device is safe and up to rigorous standards. Constraint 2 sets the maximum speed of the wheelchair at 9.32 mph, which derives from ISO 7176-6. This sets the maximum speed for an electric wheelchair at 9.32 mph [15]. Constraint 3 set the maximum weight the device and wheelchair supports at 300 lbs. This is derived from the manufacturer specifications of the weight the wheelchair that is used for testing and prototyping can support [17]. Constraint 4 considers the emergency-stop button that will be implemented in the user interface being up to the standards of other commercially used emergency stops [26]. An additional concern of the device is the heat transfer from the electrical components. For this reason, the maximum operating temperature of the electrical components and transmission is set at 158 °F. This derives from the standard temperature ratings of electronic devices which set the upper limit of temperature at 158 °F [25]. Constraint 6 ensures the device passes the static stability testing for wheelchairs set by the ISO under the standard ISO 7176-1 [15]. Similarly, ISO 7176-2 sets the standards for determining dynamic stability of the wheelchair and is intended to be followed according to Constraint 7 [15]. Both Constraint 6 & 7 ensure that the device will not make the wheelchair unsafe while it is and is not moving. Constraint 8 is also focused on safety and derives from ISO 7176-3, which specifies the test methods and effectiveness of brakes for manual and electric wheelchairs [15]. This is important to test because the main means of aiding users on declines will be through caliper brakes, which is described in Section 5.2.1. Constraint 9 is justified by ISO 7176-10. It specifies the test methods for determining the ability of the device and wheelchair to climb and descend obstacles [15]. This standard heavily covers the intended goal of the device. Constraint 10 determines the requirements and testing method as set by ISO 7176-14 for the power and control system of electric wheelchairs [15]. This constraint will be used to confirm that the device's control and power system meet the requirements of the standard. ISO 7176-25 specifies the requirements and test methods for batteries and chargers used in electric wheelchairs [15]. Constraint 11 ensures that the device's batteries meet the requirements of this standard. Design decisions have been made to address the constraints as appropriate.

Currently, the specifications, functions, and constraints are fluid as more information develops regarding industry standards and is received from talks with stakeholders, which will lead to further design development. In addition, 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.

Planned Approach - Subsystems

The wheelchair team has split up into three sub-teams to achieve the design objectives described in Section 5. The three subteams include the propulsion team, electro-mechanical integration team, and the effort sensing team. A more detailed representation of the division of responsibilities between subteams can be seen in the component integration schematic found in Figure 4. A further discussion of each subsystem, their goals, achievements, and plans for the future can be found in sections 5.2.1-5.2.3 and 5.3.1-5.3.3.



Key - Color	
	Propulsion Team
	Propulsion and Electro-Mechanical Integration Team
	Electro-Mechanical Integration Team
	Electro-Mechanical Integration and Effort Sensing Team
	Effort Sensing Team
	Propulsion and Effort Sensing Team

Key - Shape	
	Propulsion Team
	Propulsion and Electro-Mechanical Integration Team
	Electro-Mechanical Integration Team
	Electro-Mechanical Integration and Effort Sensing Team
	Effort Sensing Team
	Propulsion and Effort Sensing Team

Figure 4 Component Integration Schematic

5.1.1. Propulsion

The propulsion team is faced with the design objectives of providing positive and negative torque, eliminating jerk, and allowing folding/interfacing with common wheelchairs. The propulsion team has decided on the placement of the device, the motor type, the battery type, the attaching mechanism, the transmission system, and the braking system. The team has also created CAD models of various components of the subsystem including the attachment to the wheelchair, the hitch attachment, the transmission, the transmission housing, and torque transmitters for the wheels. Designs for the braking system, battery housing, and lifting of the device when not in use are still in progress. The full design can be seen in Figure 5.

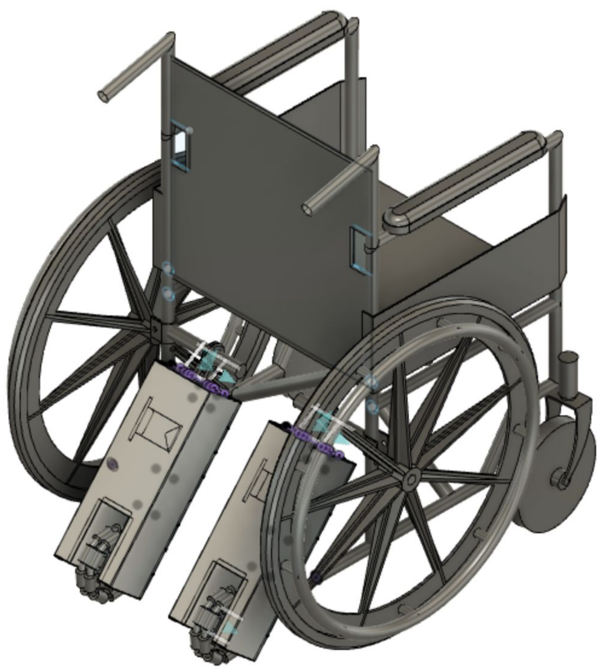


Figure 5 Propulsion Team Assembly

The propulsion team's main metrics were the cost of the device, added weight of the device, range of the device, waterproofing housing for electric components, and maximum grade (Specification 1-5). The main constraint considerations for the propulsion system are maximum added width, maximum speed of a manual wheelchair and the maximum weight (Constraint 1-3). These specifications and constraints at times competed with the desired functions of the device. In deciding the placement of the device, the conceptual designs were narrowed down 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, it would 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 requires a choice: attaching hub motors to the wheels or creating new wheels for the wheelchair that would include hub motors. This design would allow the wheelchair to fold when not in use and to interface with many common wheelchairs as it would be a single installation process. The added width of the hub motors, however, was likely to violate Constraint 1, and the added weight of the hub motors was likely to violate Specification 2 because using two motors would add approximately 20 lbs of weight [27]. For these reasons, the add-on will be attached to the back of the wheelchair, and two motors will be used to allow for steering. This design does add concerns in regard to the functionality. In particular, the added weight to the back of the wheelchair will change the center of gravity of the wheelchair. There is a concern that because stability has not yet been analyzed, the added weight and shift in center of gravity may make the device more likely to flip when going down a hill. Additionally, the propulsion system will not interface directly with the wheels of the wheelchair, making braking and going down steep inclines more difficult as braking will be attached directly to the wheels instead of done by the motor and transmission. This complicates use of the device possibly limiting the spectrum of users.

The ODrive Dual Shaft Motor - D6374 has been chosen due to the motor horsepower calculations found in Appendix B. A motor with a minimum of ⅛ horsepower is needed to move the wheelchair at 3 mph on a 12% grade. 3 mph was derived from Specification 9 & 10, because it is within the range of 2.25 mph and 9.32 mph, and 12% grade (Specification 6). 3 mph is the average walking speed of an adult, so it provides safety and keeps the motor operating above the minimum velocity [18]. The calculations for determining a ⅛ horsepower motor can be seen in Appendix B (Figure B.17). The ODrive Dual Shaft Motor -D6374 exceeds the need for ⅛ horsepower at 3.12 horsepower. The motor was chosen because it achieves the desired horsepower and was the least expensive of other fractional horsepower motors commercially available.

A 48V, 10 amp-hour battery must be used, as this was determined to provide enough energy capacity for this specific motor. To determine the capacity needed, a torque-speed curve was created from the max torque and no load speed of the motor provided by the manufacturer. This linear relationship between torque and speed allows for the torque required to go certain speeds to be determined. Using the torque required to go at a speed of roughly 3 mph, the current that each motor draws per second can be calculated by multiplying this torque by the motor's speed in rad/sec then dividing this by the voltage of the battery. Using this, the distance needed to travel, and the travel speed, the battery capacity needed can be calculated. These calculations are shown in Appendix B (Figure B.18). As determined by our calculations, this battery will allow for the user to use the device at full speed for 6 miles, and at half speed, the device can be used for approximately 13 miles. This is consistent with Specification 3 and 4. Although the total capacity was calculated, these calculations were simplified as they do not take into account any friction and assume that the user is traveling along a flat surface. The estimation, therefore, for the capacity needed is a small underestimate of how much capacity is actually needed and these calculations would not work if the wheelchair was traveling up an incline.

The component that will attach the device to the wheelchair can be seen in Figure 6. Having one attachment per side of the wheelchair will allow for the wheelchair to be partially folded. This is a design objective seen in Table 2. ANSYS analysis was done on bars that spanned the entire width of the wheelchair as well as only partially. This analysis can be seen in Appendix B (Fig B.14 - B.15). The full span was constrained with two fixed supports on either end of the bar to simulate static loading (Fig B.14). The partial span was constrained by one fixed constraint on one side to simulate static loading (Fig B.15). The full span was loaded with a load of 300 lbs to simulate the possibility of this bar withstanding the full load of the device and user (Constraint 3). This was loaded only in the negative Z direction, or towards the ground, and in the center of the bar. This does not account for the placement of the attachments or direction of the loading the entire device would have and would have been updated accordingly, but this was only used for preliminary analysis in deciding attachment placement. The partial span was loaded with 40 lbs to overestimate the maximum weight of the device of 25 lbs maximum (Specification 2). This was placed in the center of the bar where the device will be placed and is only in the direction of the ground. Further analysis will correct issues with the constraints and placements of the loads to ensure they are aligned with the expected loads and directions of the device. The initial FEA was only used to ensure either the full span or partial span would be able to withstand loading. The maximum stress in full span attachment was 9.043 ksi and the maximum stress of the partial span was 0.425 ksi. Both analyses used aluminum because it is lightweight. Both configurations kept the stress of the material below the yield stress and the displacement of each was negligible. For this reason, a partial span was chosen to allow the wheelchair to be folded while the device is attached. The V-block configuration seen in Figure 6 will allow the attachment to interface with frames of different sizes. The wing nuts allow the attachment to be easily assembled and adjusted to different wheelchair frame diameters.

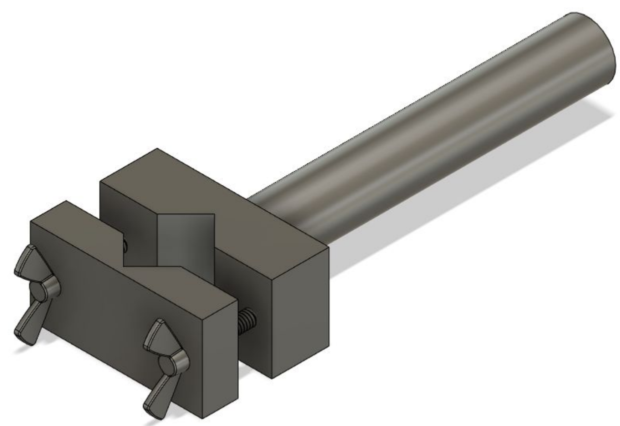


Figure 6 Attachment to the Wheelchair

Figure 7 shows the hitch attachment. This attaches to the attachment above (Fig. 6) and allows for easy installation. The purpose of the hitch is to allow for freedom of movement along the axis of the attachment it is connected to. The component is made out of aluminum to decrease weight. ANSYS analysis was done on this component and can be seen in Appendix B (Fig B.16). This shows the maximum stress as 4.11 ksi, which is below the yield stress of aluminum. The displacement of the component under loading is negligible as found through ANSYS analysis. The ANSYS analysis was loaded with one central load in the center of the plate that connects to the transmission housing in the direction of the ground. The analysis was loaded with a force of 40 lbs to be above the maximum weight set by Specification 2 of 25 lbs to ensure the device will not fail. This will need to be refined as further details of the weight and forces associated with the transmission housing are solidified to ensure that the direction and loads associated with the device are correct. The device was constrained with fixed supports on the attachment to the attachment to the wheelchair (Fig. 6) and pin connections in the pin between the circular member and the plate member. Further analysis will need to be done to ensure these calculations are correct.

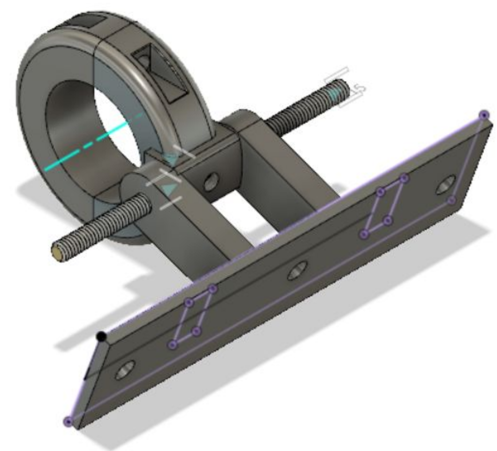


Figure 7 Hitch Attachment

A belt drive is being used for the transmission. The gear ratio for the belt drive was determined using the gear ratio calculation, which can be found in Appendix B (Figure B.20). From this code, a gear ratio of 1.3878 is needed to move a wheelchair with a person of 198 lbs 2.25 mph on a 12.5% grade (Specification 10). The housing for the transmission is shown in Figure 8. The base is made out of 3/16” aluminum and the cover is made out of 0.032” aluminum sheet metal. This component is both lightweight and weather-resistant (Specification 2 & 5) because both components are made out of aluminum.

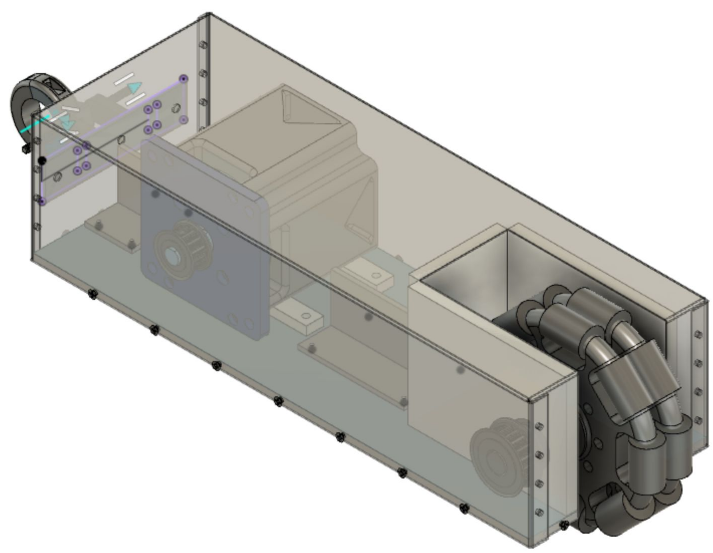


Figure 8 Transmission and Housing

Rotacaster wheels were chosen and purchased as the wheels for the device shown in Figure 8 and Figure 9. They have rollers on the extremity allowing them to roll in multiple directions. This will decrease drag when the wheelchair is turning. Additionally, a part is needed to be created to transmit torque from the axle to the wheel. The current part is seen in Figure 9. It will interface with a current hole pattern from the purchased wheels. The holes will be tapped to allow for the bolts to attach to the wheels. A piece will press-fit into a natural depression in the wheel to increase the strength of the part. A set screw will be used to ensure the wheel is turning with the axle.

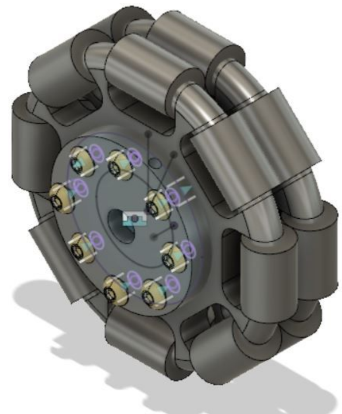


Figure 9 Wheel and Torque Transmitter

While not yet completely designed, the braking system will use caliper brakes from a bicycle. This will eventually accomplish Specification 12. Modifications will be made to allow brake handles typically used on bicycle brakes to be easily used and operated by wheelchair users that may have limited mobility or dexterity.

In order to allow for the user to use their wheelchair and not run the motor, a design to lift up the two attachments is being generated. While not completely designed, this system will include a ratcheting mechanism and cords. The purpose of this design is to prevent drag when the device is not in use.

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.

5.1.2. Electro-Mechanical Integration

The electro-mechanical integration team's current design is a human centered adjustable interface that consists of a joystick, a toggle switch for three different modes, a potentiometer to set the speed, an E-stop for an emergency, and a LCD screen for displays. The interface inputs allow the user to control the speed, the mode they are in, and the direction they are going. The system is set up so that the screen is not obstructed by the switch or joystick at most angles. The emergency stop is located on the side of the device to allow for quick reaction time and the knob is located on the other side to allow the system to be easily adjusted to accommodate left and right-handed people.

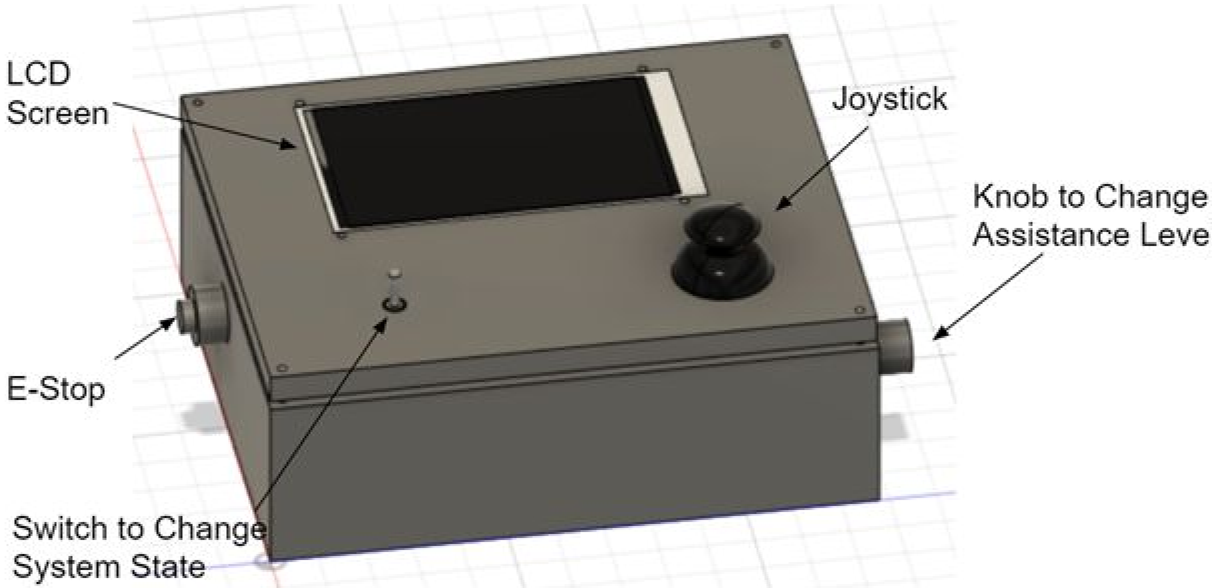


Figure 10 The user interface of the power assist

In addition, the interface will have a LCD screen that allows the user to check the system's status for things such as battery level, speed, and mode of operation. The LCD screen allows for the user to not have to remember how their wheelchair settings are configured.

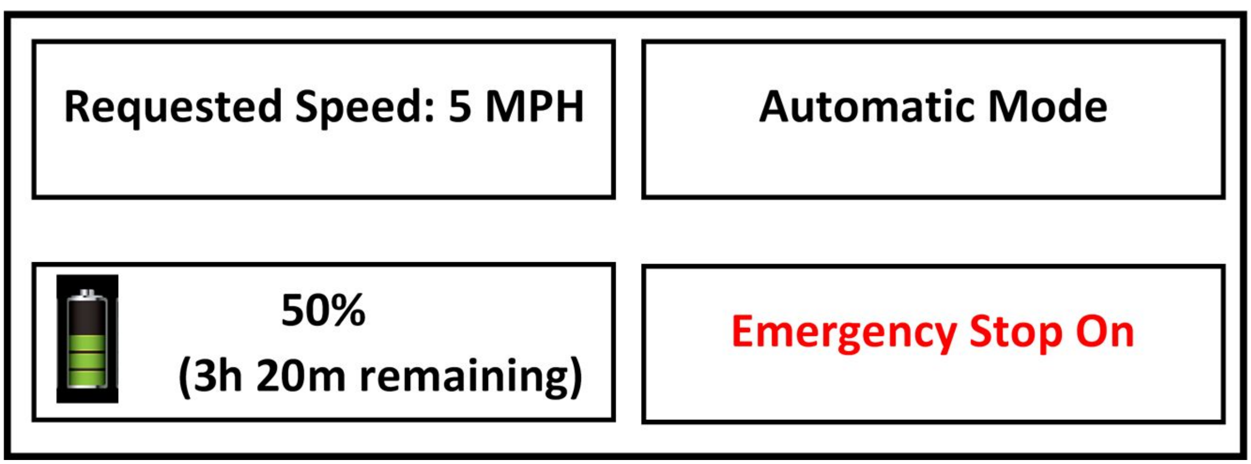


Figure 11. An example of the actual LCD screen appearance

The height of the interface can be adjusted using a spring loaded pin mechanism, similar to the ones found in crutches, so that this can be attached to various types of wheelchairs. A diagram of that can be found in Figure 12 below. A hinge will be attached to the bottom of the interface to allow the user to adjust the viewing angle in Figure 13a and 13b. For some wheelchairs, the arm rest ends prior to the end of the wheelchair arm (Figure 4a). In order to allow the device to be attached to the far arm of the wheelchair and away from the wheel of the wheelchair, there is a second, smaller adjustment mechanism that functions similarly to the primary adjustment mechanism that allows the entire user interface to be raised to the level of the arm.

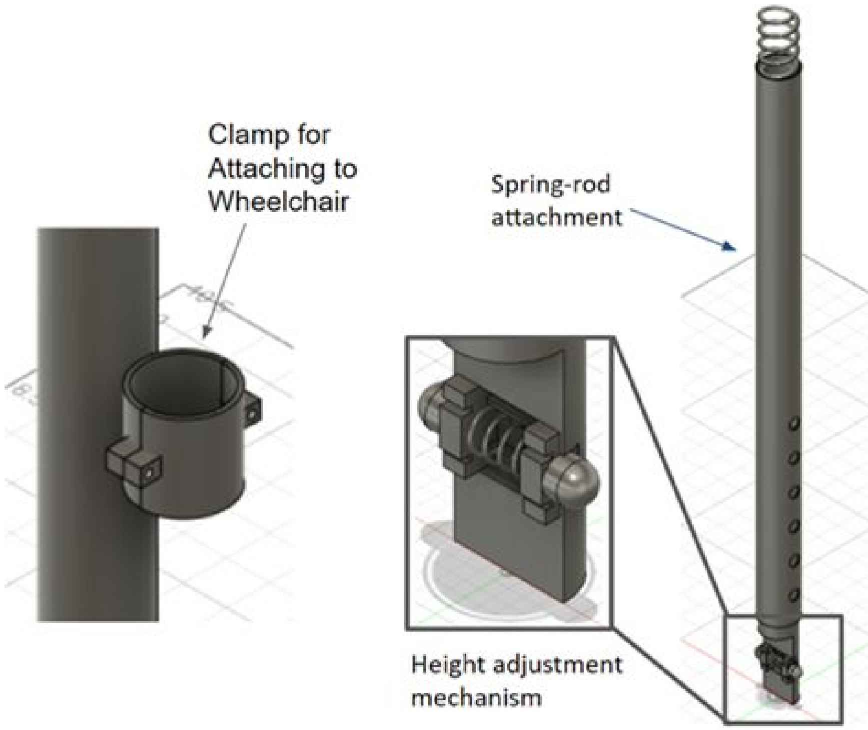


Figure 12. The adjustment mechanism for the user interface

Figure 13a (left). A wheelchair with different arm height at the attachment point. Figure 13b (right). The attachment mechanism for the user interface

The design meets the current design specifications because the interface housing and beams are made of lightweight (Specification 2) and cost effective material (Specification 1) such as aluminum, is designed for both left and right handed users, and designed to be a retro-fit option. There is intent on preventing water damage to the electronics by designing a waterproof housing for the interface (Specification 5).

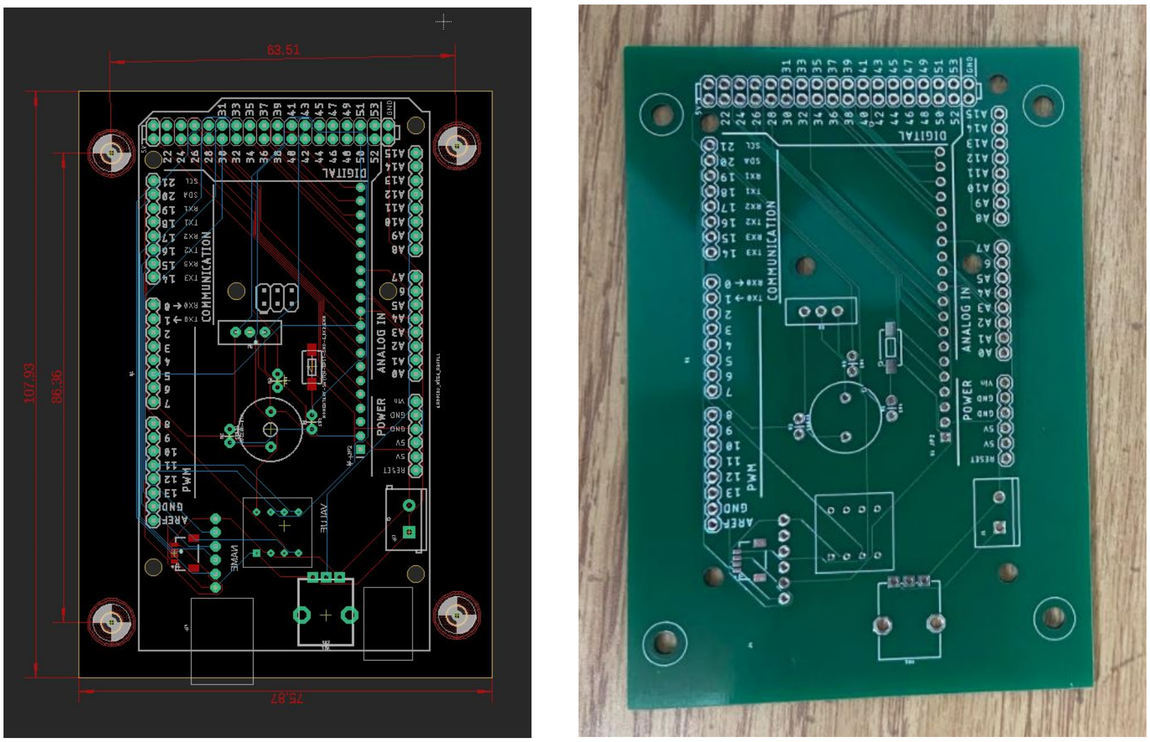


Figure 14. The designed circuit board for the interface.

During the first semester, the EMI subteam was able to design and purchase a circuit board to accommodate all components of the interface, as seen in Figure 14. The majority of prefabricated components such as a joystick, a potentiometer, an e-stop, and an LCD screen and some supplemental components such as screws, wiring, and resistors were purchased. Although no physical prototype could be fabricated prior to the end of the semester, a complete CAD model of the user interface components and their housings have been made. The CAD model consists of a box that holds all of the electronics components and a rod-pin mechanism for attaching the interface to the wheelchair.

5.1.3. <u>Effort Sensing</u>

The goal of the effort sensing team is to determine the force applied by the user which is independent of all other forces on the chair. The current design is centered around a mathematical model approach. User input can be measured directly from the user or measured indirectly by measuring the overall acceleration of the chair and using a model to find the force needed to cause this acceleration. The latter was chosen because of simplicity and preventing unnecessarily added bulk relative to other approaches. New equipment would be needed to directly measure the force from the user. Equipment of this nature, such as torque sensors or added handles, could increase the footprint of the chair, making it less accessible, or cause it to be more difficult to use. Ultimately, the mathematical approach allows the team to find user input by measuring the dynamics of the entire chair rather than finding a way to measure one intermediate force with no interference (Figure 15). The main forces that have been identified include normal force, gravity, force from the user, friction, and the force of the motor. The diagram below models the wheelchair as a point mass and neglects all moments. This is the starting point because it simplifies the model as much as possible. If it is found later that the moments significantly affect the dynamics of the chair, the model can be reevaluated.

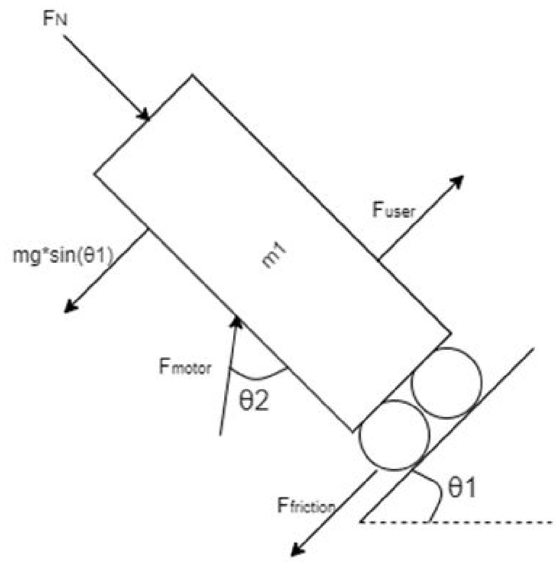


Figure 15 Free Body Diagram for Model

A systems based model (Figure 16) was used to identify inputs and outputs of the system. The input to the first block is a function of the forces mentioned above from the mathematical model and the user selected level of assistance. This block should then output the needed torque for the motor to supply. The second block will use the model of the motor to determine the voltage needed to meet this torque.

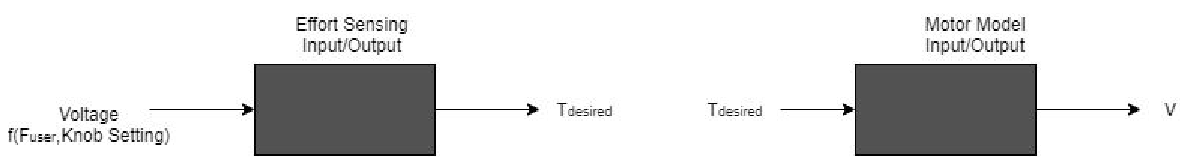


Figure 16 Input Output Model

Finally, an electric motor systems model was used to visualize and identify how input voltage relates to the output torque of the motor (Figure 17).

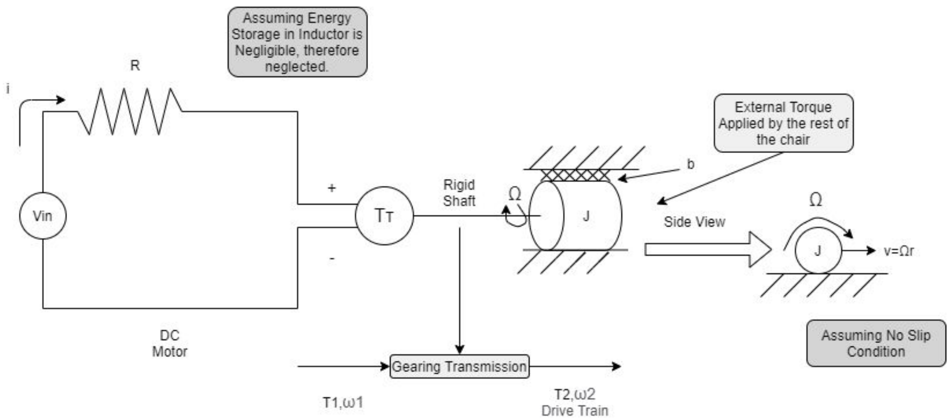


Figure 17 Physics Based Model of the Motor

A 9 degree of freedom sensor (Figure 18) was selected to measure the necessary information to implement the mathematical model. This sensor includes a gyroscope, magnetometer, and accelerometer which are built into the chip. The advantage of this sensor over an accelerometer is it allows for calculation of angle with significantly less drift. The current prototype includes the 9 degree of freedom sensor, a bread board, and a RedBoard. The bread board and the RedBoard are only used for prototype testing and will not be used in the final prototype because the sensor will be integrated into the electro-mechanical subsystem.

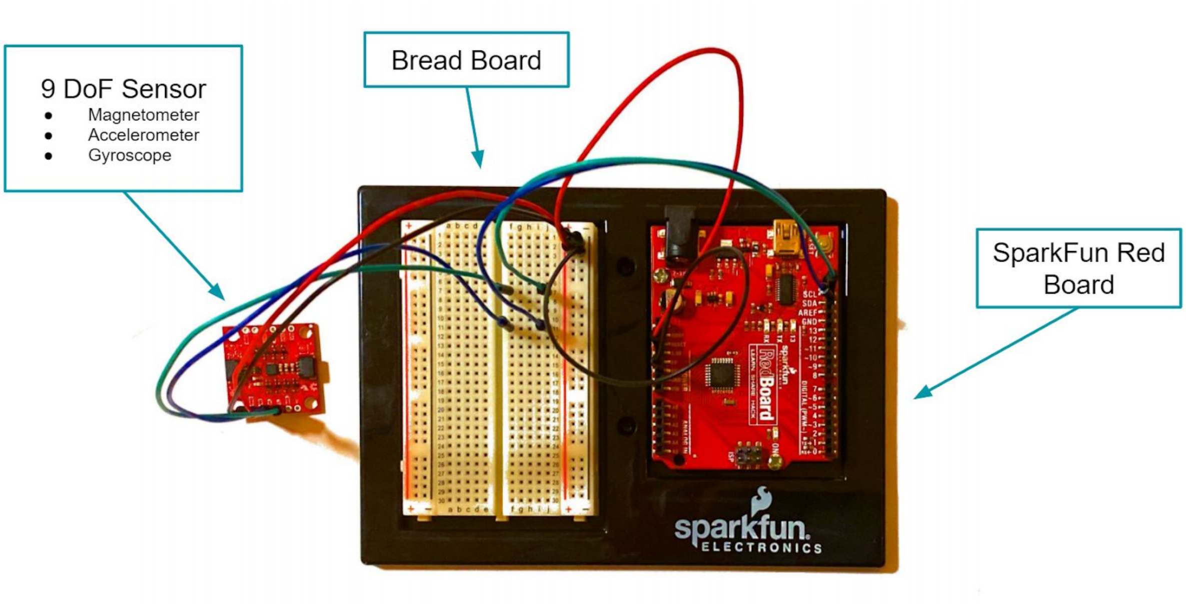
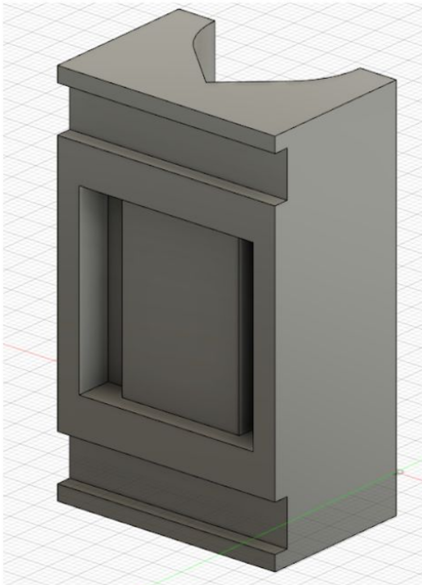


Figure 18 Current Prototype of Effort Sensing Subsystem

The current accomplishments include a physical prototype (Figure 18) from which data has been collected. Also, test housing (Figure 17) has been designed and 3D printed to aid in testing because it is essential the magnetometer be held in place to maximize accuracy of readings. This housing will not be used in the final prototype because the magnetometer will most likely be integrated into the electro-mechanical integration substeam's housing.

Test Housing CAD Model



Test Housing Physical Prototype

Figure 18 Testing Housing CAD Model and Physical Prototype

Planned Approach - Next Steps

As the project progresses, additional steps will be taken to achieve the overall goal of having a functioning device to aid manual wheelchair users to go up and down inclines and declines by May 2021. Each subsystem has their individual goals and steps to achieve this described below. The team as a whole also has steps to take to achieve this end of school year goal. Over interim the entire team will meet weekly starting in January to discuss progress of each subsystem as well as other team goals. In January, the team will also be purchasing, manufacturing, and prototyping parts and components specific to each subsystem. The team will also conduct interviews and surveys with stakeholders to elicit feedback about the current prototype and design. Design modifications will be made to address suggestions and concerns that arise from these conversations. Starting in February, parts will continue to be manufactured and prototyped. Once the team is back on campus, parts and prototypes will be assembled and tested physically. Much of the testing will be in accordance with the ISO testing methods from the standards mentioned in Section 5.1. A successful project will be a device that functions safely and suits the needs of our stakeholders.

5.1.4. Propulsion

Plans for the interim:

1. Purchase the motor, motor driver, battery, brakes, gears, and stock material (January 15, 2021)
2. Determine how we will keep a normal force on the wheel to allow for propulsion of the wheelchair (January 20, 2021)
3. Finalize CAD drawings for the attachment, hitch attachment, transmission housing, and battery housing (January 20, 2021)
4. 3D print designs to determine if any modifications need to be made (January 20, 2021)
5. Redesign any CAD models based on 3D printed prototypes (January 30, 2021)
6. Create CAD models for the braking system and lifting mechanism (February 2, 2021)

What needs to be done to accomplish end of the year goals:

1. Manufacture all of the components: attachment, hitch attachment, transmission housing, battery housing, braking system and lifting system (March 15, 2021)
2. Test the complete system (April 15, 2021)
3. Make improvements as needed (May 15, 2021)

5.1.5. Electro-Mechanical Integration

Plans for the interim:

1. Test user interface layout based on the 3D printed prototype (January 5, 2021)
2. Finalize CAD drawings for adjustment rods, interface housing, and hinge (January 8, 2021)
3. Create alternate CAD files for sheet metal manufacturing of the interface housing (January 8, 2021)
4. Finalize complete user interface assembly by combining sub assemblies (January 15, 2021)
5. Order the stock metal for the adjustment tubes (February 5, 2021)
6. Begin developing our coding approach possibly in the form of a finite state machine (February 5, 2021)

What needs to be done to accomplish end of year goals:

1. Complete the open loop controller of system (February 28, 2021)
2. Complete ANSYS modeling to determine the strength of the attachment points (February 28, 2021)
3. Conduct a heat transfer analysis to determine if a fan or heat sink is required (February 28, 2021)
4. Investigate possible waterproofing options (February 28, 2021)
5. Test the functionality of the circuit board (March 7, 2021)
6. Solder electrical components to the circuit board (March 15, 2021)
7. Manufacture and Assemble Components (March 15, 2021)

8. Test complete system (April 15, 2021)
9. Make improvements as needed (May 15, 2021)

5.1.6. Effort Sensing

Plans for the interim:

1. Convert the readings from the magnetometer into useful information (January, 16 2021)
2. Measure and calculate necessary inputs based on readings from the magnetometer (January 30, 2021)
3. Complete physical testing with the prototype in different scenarios (February 28, 2021)
4. Build a physical testing apparatus necessary for testing (January 23, 2021)

What needs to be done to accomplish end of year goals:

1. Continued testing and refining of data collection (March 7, 2021)
2. Development of the architecture of the code as well as finite state machine logic (March 7, 2021)
3. Physical integration of subsystem (April 15, 2021)
4. Software integration of subsystem (April 15, 2021)
5. Test complete system (April 15, 2021)
6. Make improvements as needed (May 15, 2021)

6. Roles and Responsibilities

The team structure is organized in various categories: team leader, assistant team leader, subteam leader/individual roles, copy editor, budget team, scribe team, sprint/schedule manager, and technical shop liaison. Outside of these roles, the team is split up into 3 groups: the propulsion team, the electrical mechanical integration team, and the effort sensing team. Each member of the wheelchair team will hold a position in their subteam as well as in the main group. Some positions are currently vacant, but will be filled by team members who do not hold positions outside of their subteam if necessary. Our team charter, which can be found in Appendix C, states that there is 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 Houser 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 team 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, finalize them, and then submit the reports. There is also 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. The individual roles within the subteams are described as secondary roles to their roles with the team.

Currently, the team leader is 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 a team was created to prevent team members from becoming overworked. The budget team is Carolyn Pye, Katie Rice and Emily Eng. The sprint/schedule leader is Drew Freeland. Nicole Stanec is the technical shop liaison, and the copy editors will rotate with each report. Emily Eng and Carolyn Pye are part of the IRB team and are working with Professor Nees and Professor Vinchur. The first copy editors were Charlotte and Nicole, and Emily and Drew were the copy editors for the second report. Currently, the copy editors are Charlotte and Nicole. 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 year, this will change when the unfilled roles need someone to take responsibility.

Within the subteams, each member of the class has a position. 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 Section 5.2.1. The Electro-mechanical team is 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 neither have specified roles. In the propulsion group, Nicole is the subteam leader and each member has aspects on which they will focus. Charlotte is in charge of the ISO information, wheel, hitch, torque transmitter and braking. Katie is responsible for the motors, attachment, lifting mechanism and the subteqam budget. Geoffrey is in charge of the batteries. Nicole is in charge of the transmission, transmission housing and motors. All of these teams are integrated with one another, so although everyone has a designated team, there is frequent collaboration on all aspects of the project. There is frequent communication among the team to ensure that all aspects of the project are covered. 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	Propulsion
Charlotte	Team leader, part of scribe team	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 member	Propulsion
Katie	Part of budget team, member of scribe team	Propulsion

Members of the team are expected to maintain a level of professionalism and respect. The benefit of the doubt is given to everyone and sets up the team success. Each person will be held accountable and will hold each other accountable. Communication is the key to success, so open communication is essential. In order to have open communication, all members are expected to be at meetings and let everyone know if they will not be attending. Members are conscious of the way they interact with one another and remember to be open and respectful. 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.

7. 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 [28] was implemented. 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 two week period. 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 implemented 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 time allowed enough time for team members to revise any parts of the report as well as for Professor Utter to offer any feedback. Additionally, this extra time gave the copy editors enough time to look through reports and for any team members to complete missing or unfinished sections 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 on conducting interviews with wheelchair users and on sending out surveys, found in Appendix D, to related healthcare professionals, the responses to both of which will help the team further refine the final design.

The team used 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 worked through tasks, the color of each task changed to represent progress from future event to current event then to complete. Each group of tasks is color coordinated by the subsystem in the leftmost column.

Each subteam has completed their respective goals. Each team has already decided the components they need and created full CAD assemblies. The Electro-Mechanical Integration team has already gathered all of the subsystem components and the Effort Sensing and Propulsion subteams have completed mathematical models and analyses including structural and thermodynamic evaluations. For further information on the subteams' current progress and next steps, please refer to sections 5.2 and 5.3 respectively.

The team goal for the end of the semester was to have a completed CAD model of each subsystem 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 has put the team in a good position to complete a fully functional wheelchair add-on by the end of the school year.

8. Required Resources

Table 7 is a bill of materials for the prototype, including stock material and fasteners. The components are organized by subteam and all sources for pricing may be found in Budget References under the corresponding numbers. The team made an effort to minimize price without sacrificing quality. The estimated total cost of the prototype is currently $1,327.07. This price may fluctuate as other systems are added and parts are improved, but it is estimated to stay within the $1,400-1,600 range. This price successfully satisfies the metric for the cost to not exceed $2,500 (Specification 1). Since the team requires extra items for testing, such as the wheelchair base model and independent control systems, additional parts have been purchased to allow team members to build mini prototypes and conduct tests in various locations. The additional purchases are listed in Table 8, with pricing references shown under corresponding numbers in the Budget Resources. Currently, the total extra expenses sum to $245.25, which is expected to increase depending on whether team members can work in the same locations with the same parts in the spring or if we will need to order extra components.

Table 7: Prototype Bill of Materials

Subteam	Component	Description	Unit Cost	Quantity	Total Cost
Electrical and Mechanical Integration	Mini Speaker [1]	for user interface, PC Mount 12mm 2.048kHz	$1.95	1	$1.95
	Arduino Mega 2560 R3 [2]	control system inputs and outputs	$38.95	1	$38.95
	Toggle Switch [3]	for user interface, 125 VAC	$2.95	1	$2.95
	GTE Knob [4]	for user interface, small	$0.95	1	$0.95
	Ribbon Cable [5]	connectors, 10 wire (15ft)	$4.95	1	$4.95
	Rotary Potentiometer [6]	for user interface, Linear (10k ohm)	$0.95	1	$0.95
	Touchscreen Breakout Board [7]	for user interface, 3.5" TFT 320x480 + with MicroSD Socket - HXD8357D	$39.95	1	$39.95
	SPST Latching Pushbutton Switch [8]	for user interface	$7.81	1	$7.81
	Compression Spring Stock [9]	for user interface attachment, 36" Long, 0.75" OD, 0.59" ID	$4.69	1	$4.69
	Compression Spring (pack of 12) [10]	for user interface attachment, 0.75" Long, 0.24" OD, 0.196" ID	$10.84	1	$10.84
	Screw Terminal [11]	for control system	$0.95	1	$0.95
	10K Ohm Resistor (pack of 20) [12]	for control system	$1.20	1	$1.20
	Circuit Board [13]	for control system	$1.28	1	$1.28
	General Purpose Aluminum Tubing [14]	for user interface attachment, 7/8" OD, 0.035" Wall Thickness, 3 ft long	$12.25	1	$12.25
	General Purpose Aluminum Tubing [15]	for user interface attachment, 1" OD, 0.058" Wall Thickness, 3 ft long	$22.32	1	$22.32
	Thumb Joystick [16]	for user interface	$3.95	1	$3.95
Propulsion	ODrive Dual Shaft Motor [17]	high torque motor to propel device, D6374 150KV	$99.00	2	$198.00
	Magliner 130502 Rotacaster Double Row Multi-Directional Wheels	turned by motor to propel device	$24.99	2	$49.98

	[18]				
	Motor Encoders [19]	provides motor counts, 8192 CPR Encoder with Cable	$39.00	2	$78.00
	ODrive Motor Driver [20]	connects control system and motor, V3.6 56V with connectors	$159.00	1	$159.00
	Timing Pulley: 20 teeth [21]	for transmission	$13.31	2	$26.62
	Timing Pulley: 14 teeth [22]	for transmission	$10.30	2	$20.60
	L Series Timing Belt [23]	for transmission	$8.11	2	$16.22
	Ball bearing [24]	for transmission, Open, Trade Number R8, for 1/2" Shaft Diameter	$6.27	4	$25.08
	Rotary Shaft [25]	for transmission, 1566 Carbon Steel, 1/2" Diameter, 24" Long	$17.81	1	$17.81
	P3316 Aluminum 3003 H-14 Plate [26]	transmission housing base plate, 2ft x 1 ft, 3/16" thick	$41.56	1	$41.56
	Multipurpose 6061 Aluminum T-bar [27]	transmission housing support, 2 ft	$13.91	1	$13.91
	Sheet metal [28]	transmission housing, 0.032" thick, 2ft by 4 ft, S3032	$73.40	1	$73.40
	Rivets (pack of 10) [29]	for transmission housing, Aluminum, 1/8" Diameter, for 0.063"-0.125" Thickness	$9.75	1	$9.75
	Flat head screws (packs of 10) [30]	for transmission housing, 4-40 Thread Size, 1/2" long	$9.43	3	$28.29
	High-Strength Steel Threaded Rod [31]	for hitch attachment, 8-32 Thread Size 4" Long	$1.67	2	$3.34
	Zinc-Plated Steel Wing Nut (pack of 100) [32]	for hitch attachment, 8-32 Thread Size	$9.23	1	$9.23
	Alloy Steel Cup-Point Set Screw Black-Oxide (pack of 100) [33]	for torque transmitter, 10-32 Thread 3/8" Long	$13.06	1	$13.06
	Plastic-Head Thumb Screws (pack of 10) [34]	for hitch attachment, two-arm, 10-32 Thread, 3/8" Long	$7.25	3	$21.75
	Stainless Steel Button Head Hex Drive Screw (pack of 100) [35]	for hitch attachment, 18-8, 8-32 Thread Size, 1-1/4" Long	$8.56	1	$8.56

	Low-Strength Steel Hex Nut (pack of 100) [36]	for hitch attachment, Zinc-Plated, 8-32 Thread Size	$1.65	1	$1.65
	F4182 6061-T6511 Aluminum Flat [37]	for hitch attachment, 1/8 X 2"	$4.96	1	$4.96
	F41412 6061-T6511 Aluminum Flat [37]	for hitch attachment, 1/4 X 1/2"	$4.12	1	$4.12
	R3158 6061-T6511 Aluminum Round Bar [38]	for hitch attachment, 1-5/8 inch Dia., 1 ft long	$20.30	1	$20.30
	Ultra-Machinable 360 Brass Disc	for torque transmitter, 1-1/2" Diameter 1/2 ft	$36.17	1	$36.17
	F41112 6061-T6511 Aluminum Flat Bar [37]	for attachment to wheelchair, 1 X 1-1/2, 1 ft. long	$12.99	1	$12.99
	Multipurpose 6061 Aluminum Rod [39]	for attachment to wheelchair 1" Diameter, 1 ft Long	$6.60	1	$6.60
	Stainless Steel Wing-Head Thumb Screw [40]	for attachment to wheelchair, 1/4"-20 Thread Size, 2" Long	$10.08	4	$40.32
	Gasket Material [41]	for attachment to wheelchair, Water- and Steam-Resistant EPDM, 12" x 12", 1/16" Thick	$4.92	1	$4.92
	Lithium Ion Battery [42]	for powering the system, 48 V, 10 AH	$189.00	1	$189.00
	Bike Caliper Brakes [43]	for breaking	$18.99	1	$18.99
Sensor	SparkFun 9DoF IMU Breakout [44]	for user input detection	$16.95	1	$16.95
				Total	$1,327.07

Table 8: Additional Expenses Estimate

Subteam	Component	Description	Unit Cost	Quantity	Total Cost
all	Wheelchair [45]	base model for prototype testing, Drive Medical Silver Sport 1	$109.29	1	$109.29
Electrical and Mechanical Integration	Mini Speaker [1]	extra for prototype, PC Mount 12mm 2.048kHz	$1.95	1	$1.95
	Toggle Switch [3]	extra for prototype, 125 VAC	$2.95	1	$2.95
	GTE Knob [4]	extra for prototype, small	$0.95	1	$0.95
	Rotary Potentiometer [6]	extra for prototype, Linear (10k ohm)	$0.95	1	$0.95
	Compression Spring Stock [9]	extra for prototype, 36" Long, 0.75" OD, 0.59" ID	$4.69	1	$4.69
	Screw Terminal [11]	extra for prototype	$0.95	1	$0.95
	Circuit Board [13]	extra for prototype	$1.28	4	$5.12
	Break Away Headers - Straight [46]	for testing	$1.50	5	$7.50
	Female Headers [47]	for testing	$1.50	5	$7.50
	Panel Mount Momentary Pushbutton [48]	replaced emergency stop button, 16 mm, Red	$0.95	1	$0.95
	Solder Wire [49]	for assembly, 60/40 Rosin Core - 0.5mm/0.02" diameter - 50 grams	$5.95	2	$11.90
	Arcade Joystick [50]	replaced joystick	$19.95	1	$19.95
	Breadboard [51]	for testing	$4.95	2	$9.90
	M/F Connector [52]	for testing	$1.95	1	$1.95
	F/F Connector [53]	for testing	$1.95	1	$1.95
	M/M Connector [54]	for testing	$1.95	1	$1.95
Sensor	SparkFun 9DoF IMU Breakout [44]	extra for prototype	$16.95	1	$16.95
	MOD ADXL335 accelerometer [55]	replaced sensor, 5V READY 3AXIS +-3G	$14.95	1	$14.95
	Arduino Uno R3 [56]	for testing	$22.95	1	$22.95
				Total	$245.25

Once the components have been purchased for the prototype, the team will need time, space, and tools to assemble and store the prototype. The spaces used thus far have been team member's homes both on and off campus. The team intends to use Leopard Works room 006 to work together to assemble the prototype. Additionally, the team will be manufacturing components in the machine shop and with 3-D printers. If this is not possible, the team will continue to test subsystems remotely and find another way to assemble a prototype. A series of experimental tests will be conducted to determine the strengths and weaknesses of the prototype. The tests will assess weight, speed, maneuverability, range, and response to user input. They will initially be conducted using an object, such as a sack of potatoes, to ensure that the prototype is safe to use. Once the prototype is confirmed to be safe enough for human use and the risk of injury is greatly reduced, members of the team will begin testing the device by using it themselves. The tests will take place on various straightaways, inclines, and declines on campus. These locations will include ramps to enter buildings, hallways, sidewalks outside of Acopian Engineering Center, the hills by Acopian Engineering Center, Sullivan Street, Hamilton Street, and more. Outdoor testing will be dependent on the weather conditions. The team will need to physically transport the prototype to these locations. The results of the tests will inform how the team moves forward in the design process.

Additionally, the prototype will be further refined by the results of the surveys and interviews with people who use wheelchairs and healthcare professionals conducted in accordance with IRB guidelines. It is important to get input directly from the target audience to ensure that their needs are met. This is discussed further in Section 9 and Appendix D.

The testing and feedback from the surveys and interviews is expected to result in multiple prototype iterations. As a result, the bill of materials, additional expenses, and total budget for the team is anticipated to increase. However, the team intends to limit the increase in the cost of the prototype while maintaining product quality in accordance with the design objectives.

9. 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.

The team has consulted a combination of individuals with technical backgrounds and individuals who have experience working with or using wheelchairs. The team completed an IRB application and received approval. The team has begun to gather information from a variety of healthcare professionals and wheelchair users by conducting the surveys and interviews that were approved by the IRB committee. The team conducted our first interview with a wheelchair user who expressed his excitement for the new technology and his appreciation for being included in the project. Some of the preliminary feedback includes an emphasis on keeping the device lightweight and some concerns about placing hands near the moving spokes of the wheels. Additional interviews are being scheduled for completion during the interim. The team has also begun sending out surveys to healthcare providers 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 survey and interview more people with the help of the connections of team members as well as the individuals who were interviewed using the survey questions found in Appendix D. The current survey results are inconclusive due to a low number of initial responses. The team is working on making the processes of completing the survey easier with the hopes of obtaining more responses. The team hopes that the surveys and interview will provide us with 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 and survey are friends or relatives who have already agreed to help.

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. In addition to Professor Utter, the team has begun consulting 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, specifically the use of sheet metal for some of the metal housings. 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.

10. 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 safety. The team needs to ensure that all team members and wheelchair users are out of harm's way at all times. When considering safety, there are concerns regarding 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. The testing will follow ISO 7176 guidelines and practices as shown in Table 4 and 5 above [20].

Additionally, we are concerned with electrical failure and the waterproofing of all of the electrical components of the design. Electrical failure could result in both a broken wheelchair and an injured wheelchair user making it a top priority. 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, the team is 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 potentially injuring the person in it. In order to mitigate this risk, center of mass calculations will be done 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. The team is planning on establishing any necessary training materials with the hope that the human-centered design will make the system largely intuitive. Finally, any additional safety mechanisms that can be used to prevent unnecessary harm to the user are continually sought as the project progresses.

11. Team Self-Examination

The team is progressing well with the overall goals of the project. The goal for the end of the semester was to accomplish a well developed CAD model of each subsystem prototype and having a full bill of materials. This has been accomplished besides some aspects of the propulsion team including the braking system and a lifting mechanism. These will be worked on over the interim to allow for manufacturing at the beginning of the next semester. Further prototype refinements for the completed CAD models will occur over the course of the year but solid CAD models have been developed for the majority of the components of the device. The team overall has worked well together over the course of the semester. The team is generally good at meeting internal deadlines for rough and final drafts. The team is always productive during set class times, especially the lab periods. As stated in the team charter (Appendix C), every member was expected and has shown up to class on time and ready to work. Despite the challenges associated with online learning, group discussions have been largely engaging and productive. The structure of the team has remained consistent throughout the semester once subteams were created and subteam leaders were chosen. The assistant leader position has still not been filled, but may be filled in the future. As a whole the team works well together and is productive.

11.1. Propulsion Team’s Self-Examination

The propulsion team works well together. Expectations of members are set and most members achieve their set goals in a timely manner, and are responsive to other members' communications and feedback. The team has accomplished a lot over the semester including CAD drawings and bill of materials for the transmission, motor, motor driver, attachment, and hitch. The battery, lifting system, and brakes need further CAD models, but serious progress has been made on each of these. Nicole Stanec, the leader of the subteam has done an excellent job delegating work and set expectations high. The team dynamic is great and communication is very effective amongst most team members. The team is good at being on schedule and the team meetings are always organized and productive. As a whole the subteam has done a great job of achieving internal goals and deadlines.

11.2. Electro-Mechanical Integration Team's Self-Examination

The electro-mechanical integration team has made great strides in achieving the semester goals. The team has completed CAD models and circuit boards which were primary goals for the semester. The team hoped to finish some coding and ANSYS modeling this semester. Upon beginning an Finite State Machine (FSM), it was determined that more research and testing was needed to complete the FSM because components that were planned on continued to change throughout the semester. Additionally, the CAD modelling proved more complex than initially expected so the team decided to move the ANSYS modeling to winter break.

Our team structure remains relatively loose over the first semester with everyone checking on each other to ensure that everything was on track for completion. One primary clarification to our team structure was that Carolyn would communicate the subteam progress with the rest of the subteams. Overall, the EMI team works very well together and has maintained good communication and continuous progress over the course of the semester.

11.3. Effort Sensing Team's Self-Examination

The effort sensing team has been progressing well and making efficient progress throughout the semester. Expectations and roles are understood and clearly defined. Even as new deliverables come up, the work is properly addressed and delegated as necessary. The structure of no specific leader works well for this group because there is an even amount of responsibility and members of the subteam are held accountable for their responsibilities with there being only two subteam members. No specific changes have been made to the structure. Overall, the subteam has produced on time, organized, and quality work for the subsystem. Open lines of communication and an overall honest dynamic have contributed to the success during this semester.

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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) [3].

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.

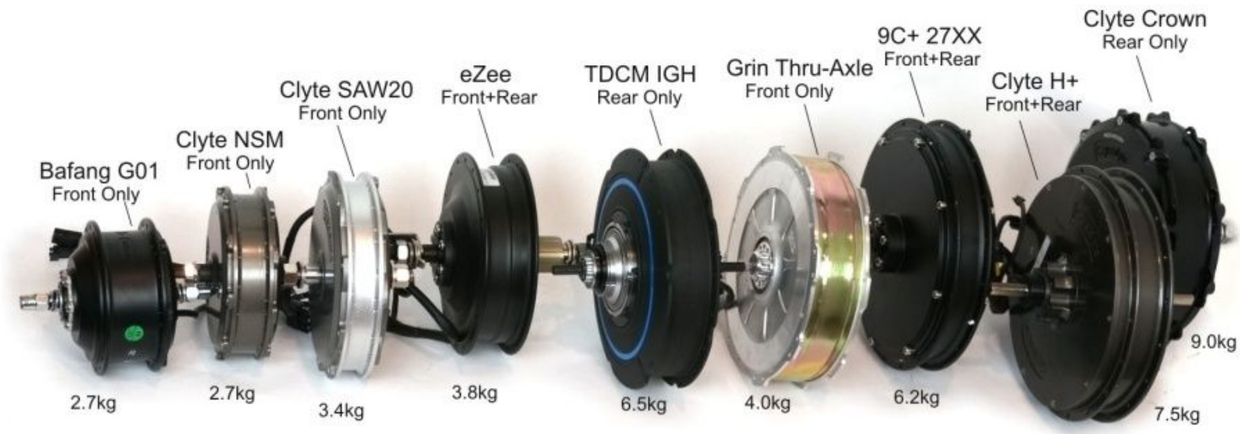


Figure A.1 Hub Motors used in E-Bikes [13]

Figure A.2 Hub Motor in E-Bike Wheel [13]

Appendix B: Conceptual Designs and Calculations for the Planned Approach

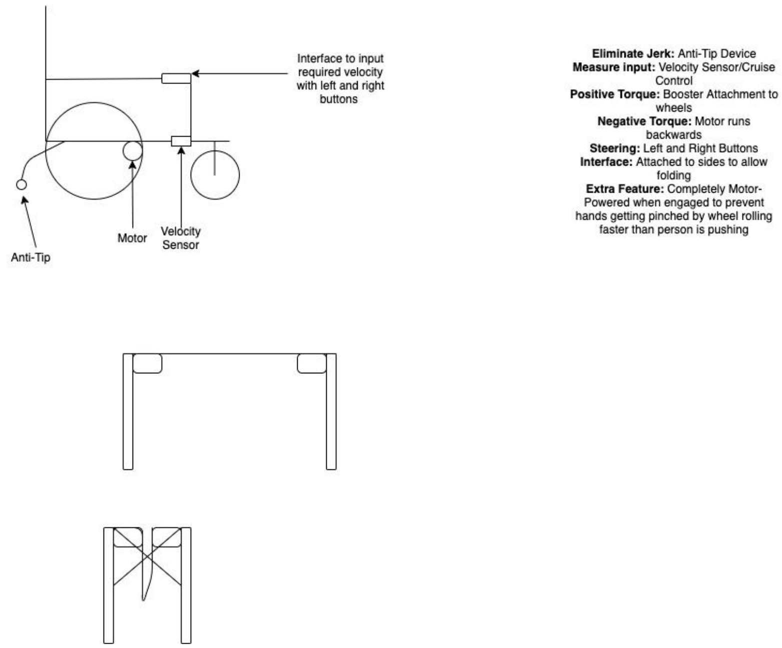


Figure B.1 Wheelchair design with motor-driven wheels

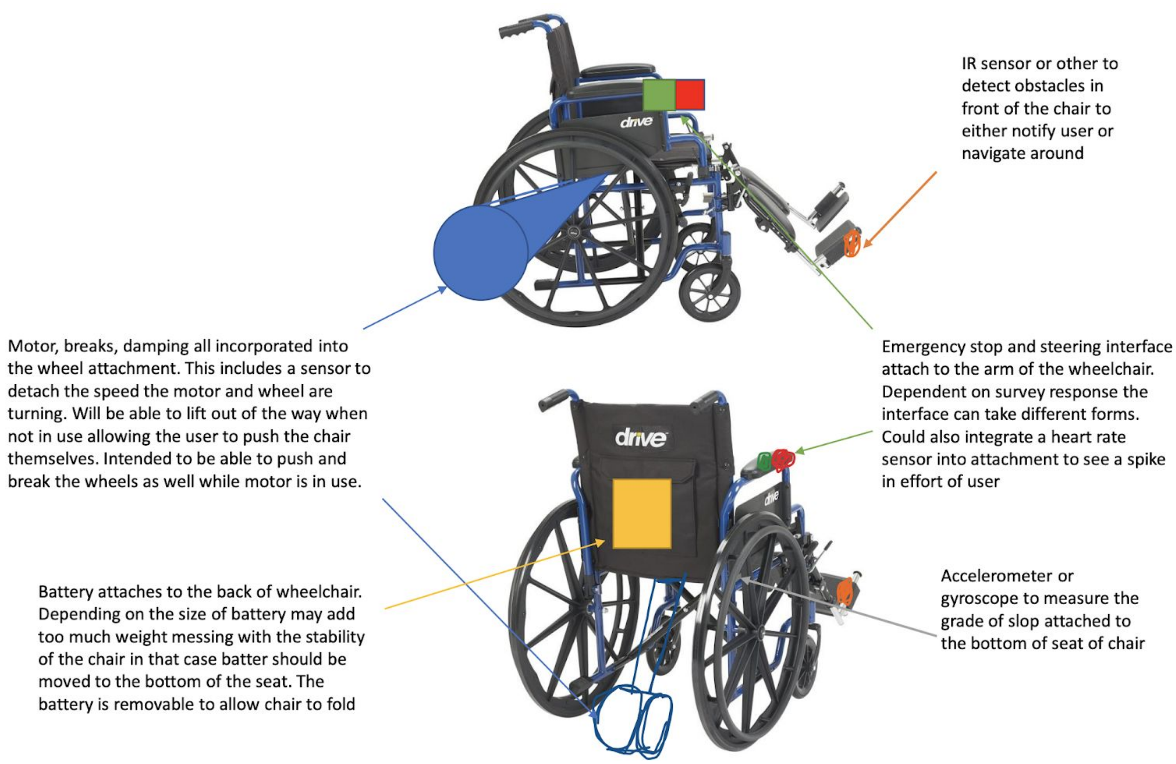


Figure B.2 Attachable wheel to the back of the wheelchair[17, modified]

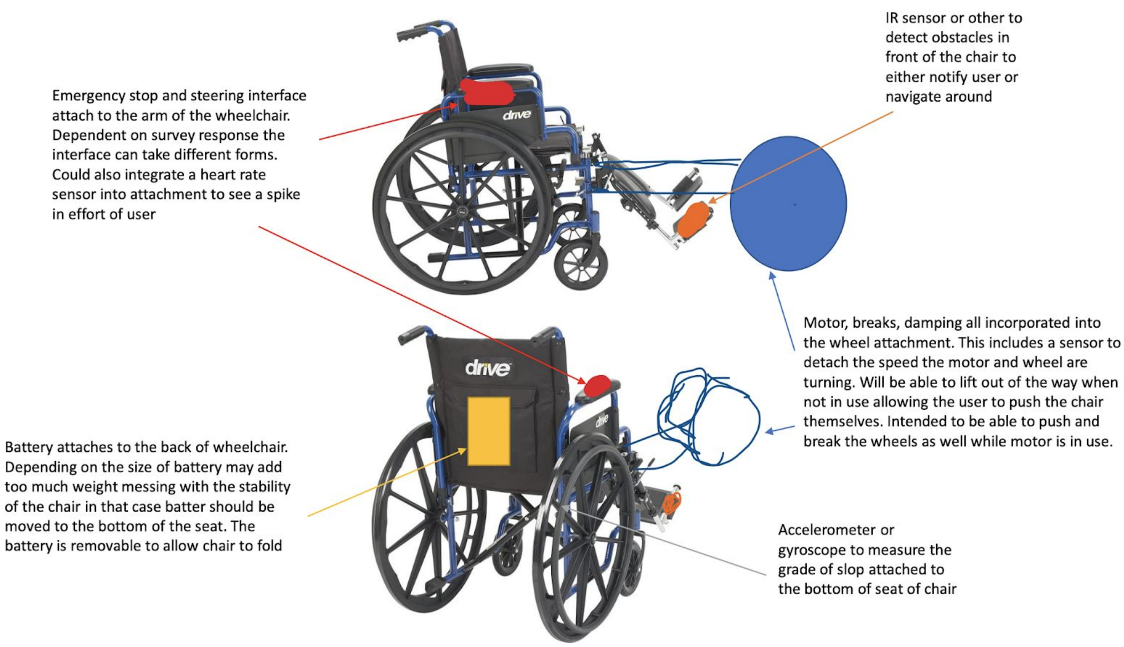


Figure B.3 Attachable wheel to the front of the wheelchair [17, modified]

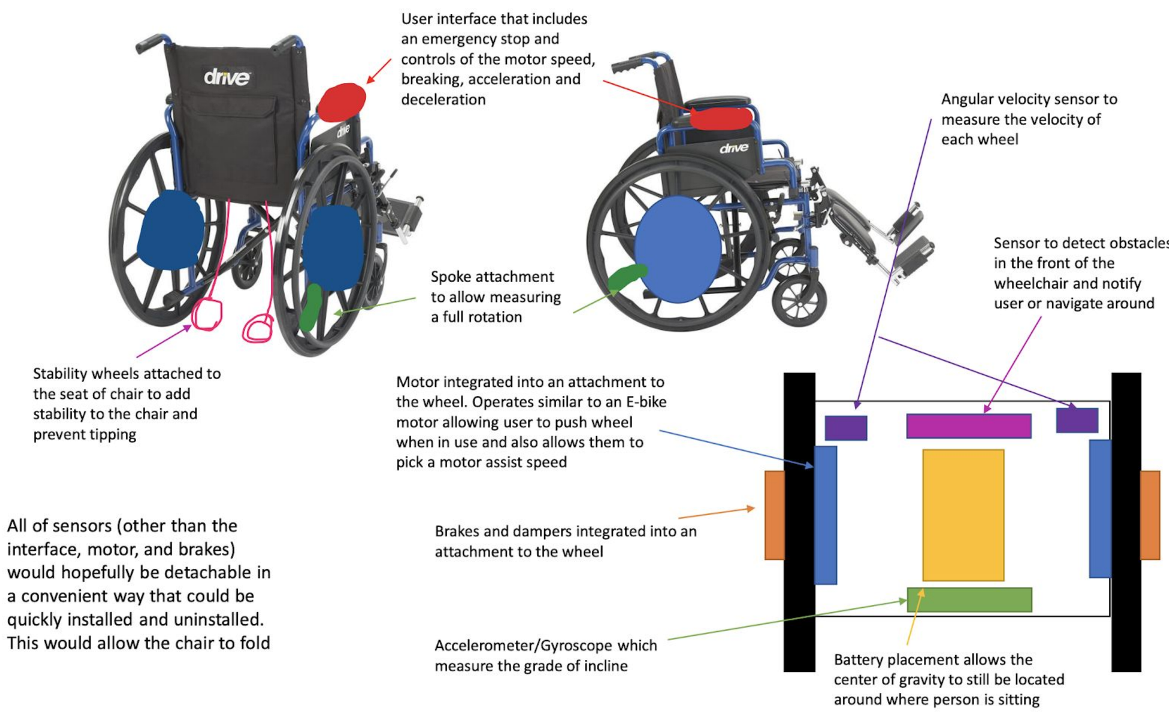


Figure B.4 E-bike mechanism design with layout of various components under the seat [17, modified]

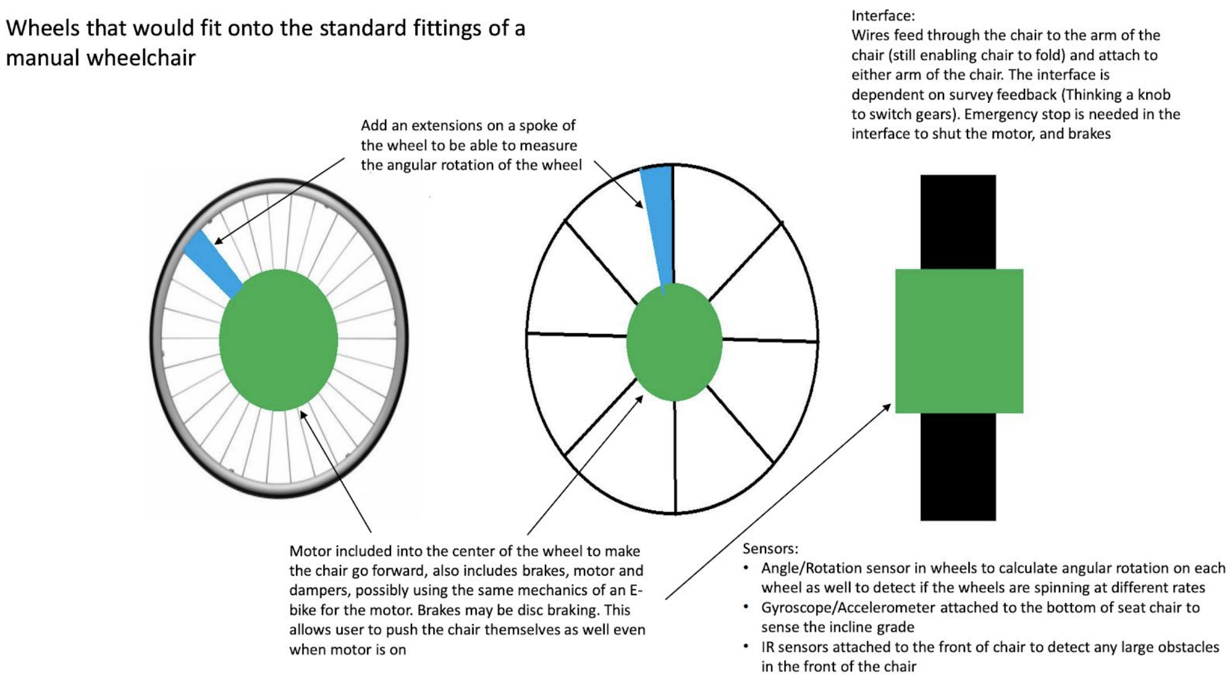


Figure B.5 Detachable wheels powered by motors at the hub

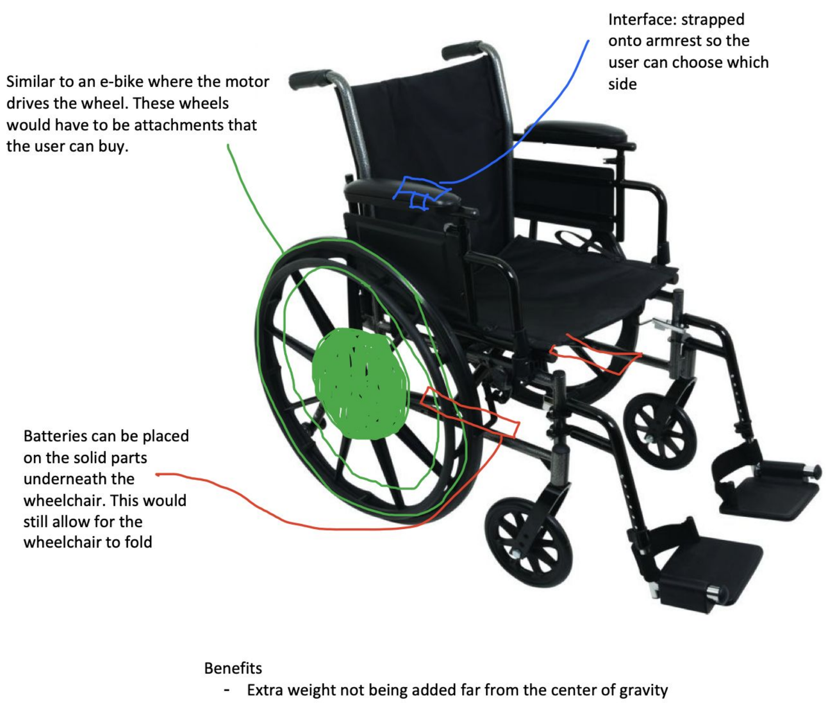
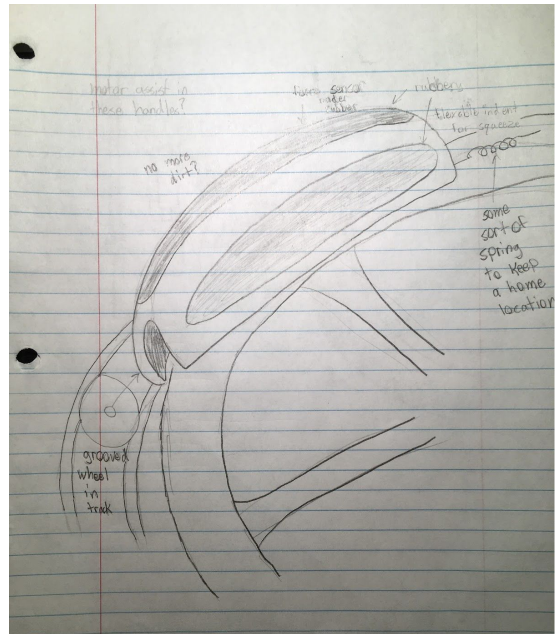


Figure B.6 Wheelchair design with new wheel attachments [29, modified]

(a)

(b)



(c)

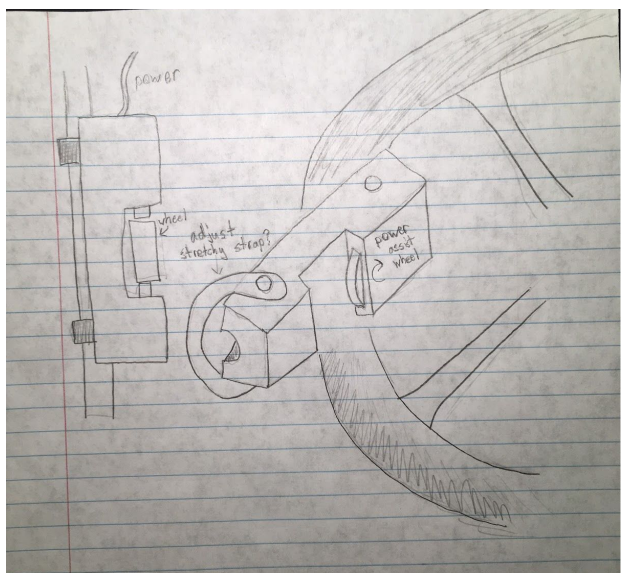


Figure B.7 (a) Overall wheelchair design (b) Force sensor design (c) Motor Attachment

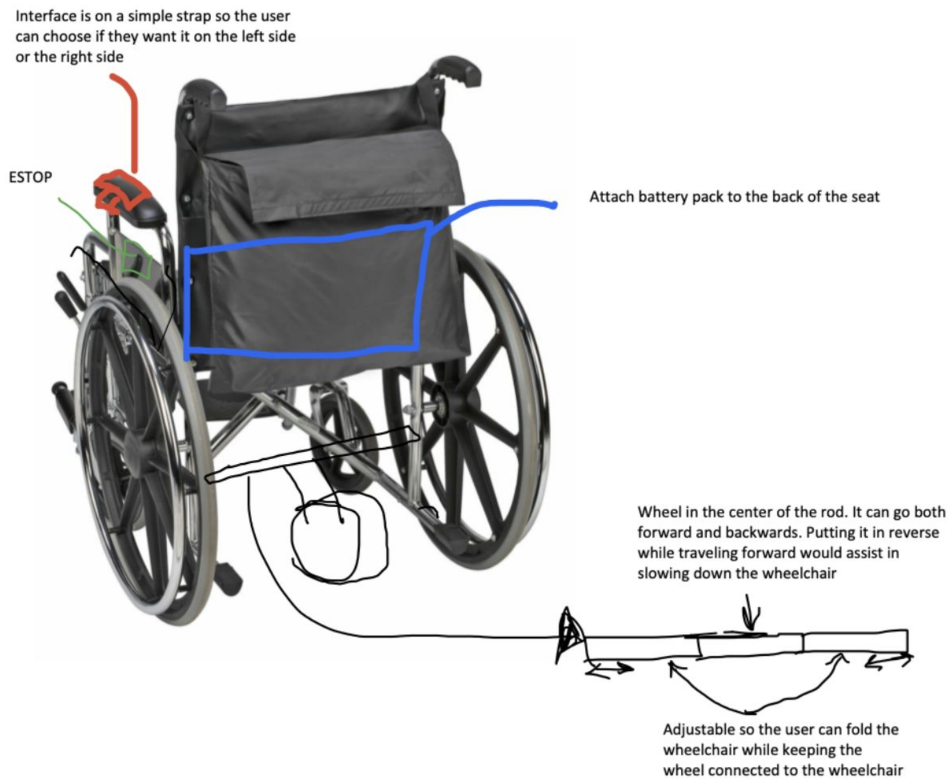


Figure B.8 Rear wheel addition with expandable bar[29, modified]

Figure B.9 Option for where we can place batteries, Estop, user interface and speedometer [5, modified]

(a) (b)

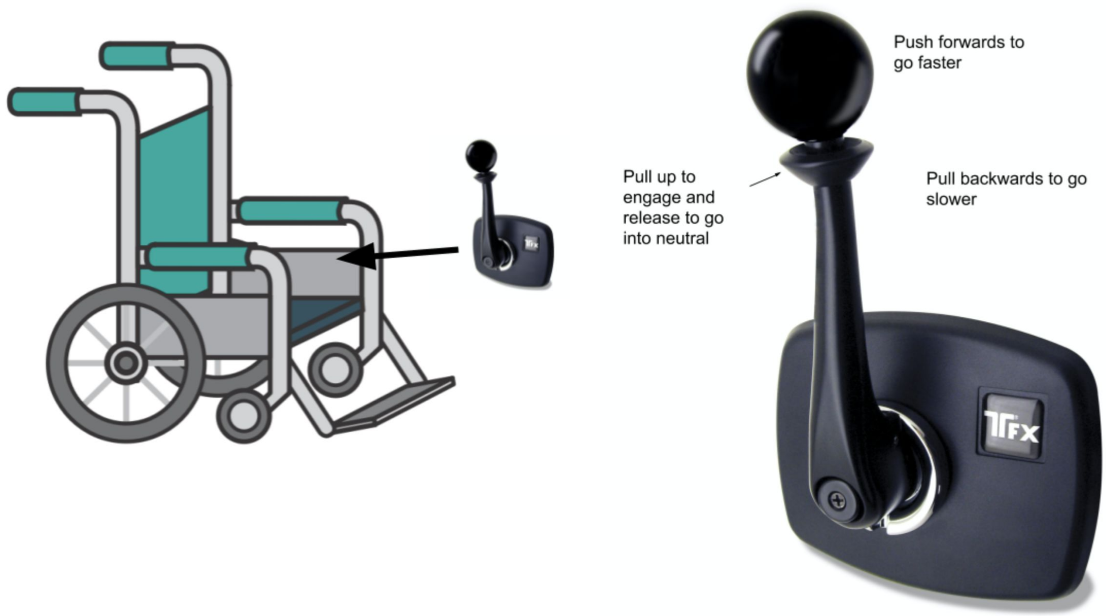


Figure B.10 (a) Placement of throttle (b) Throttle with description of mechanism [30, 31, modified]

Figure B.11 Placement of batteries and sensors [32, modified]

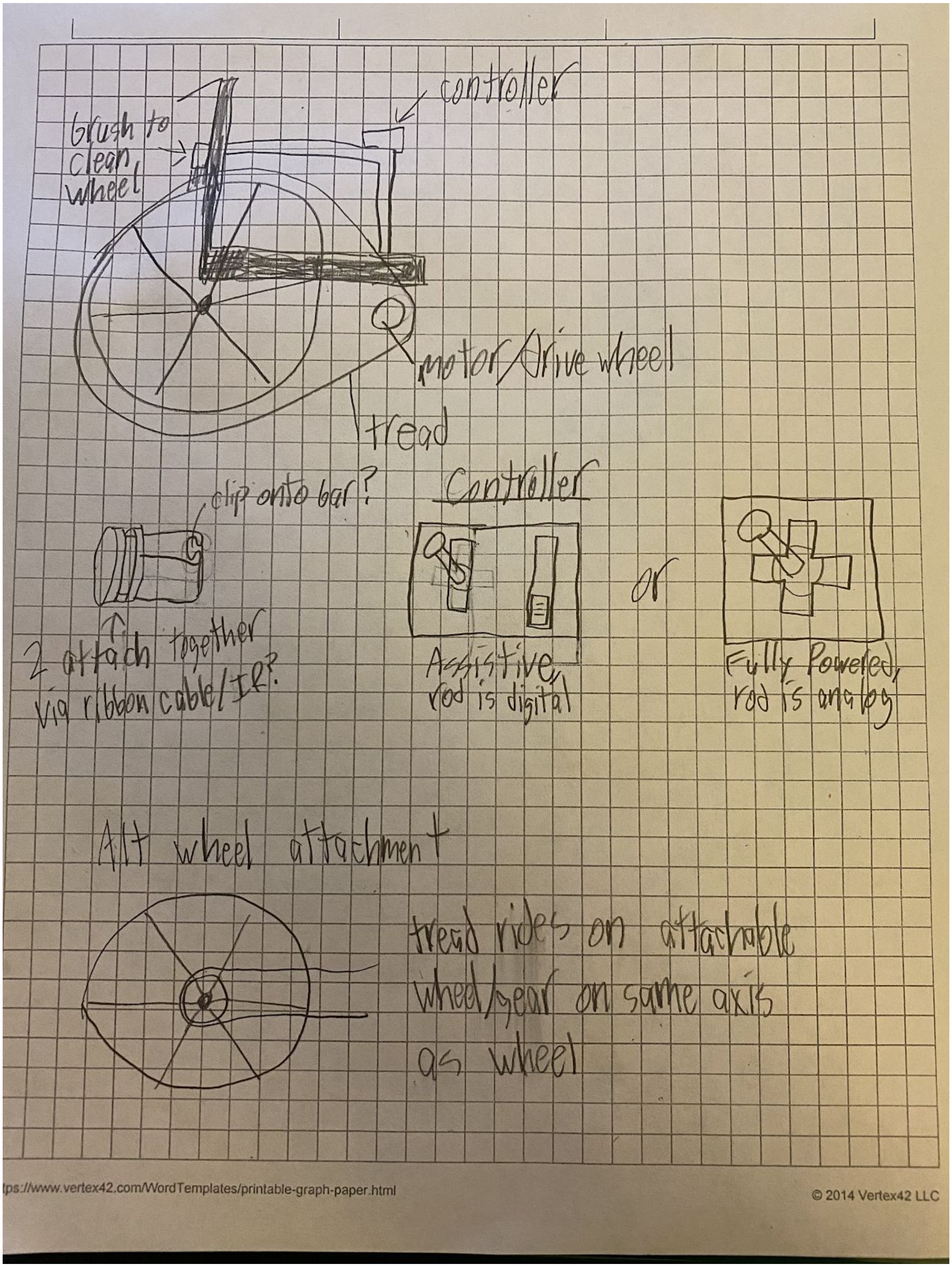


Figure B.12 Motor/drive wheel with a description of a controller

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?

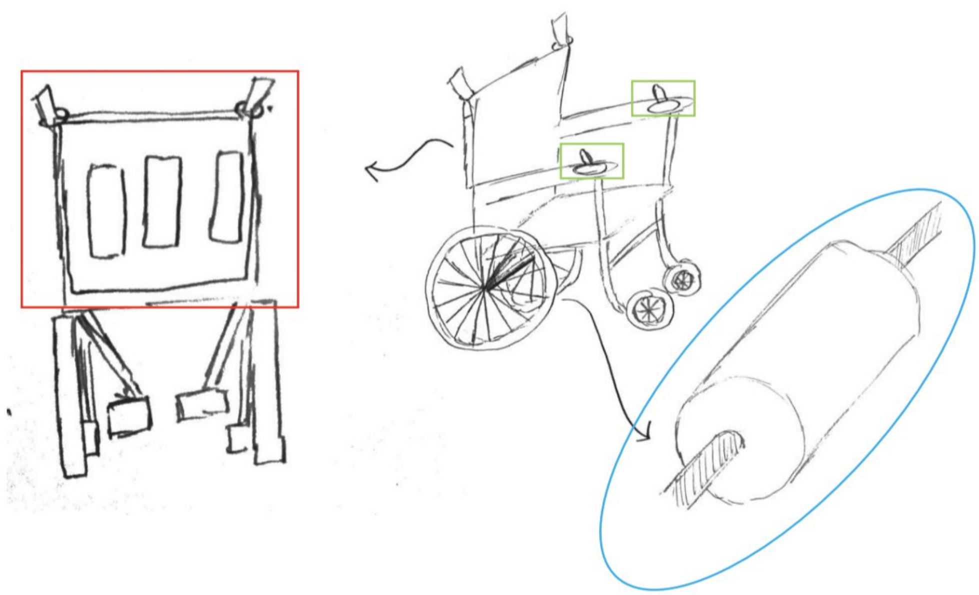


Figure B.13 Wheelchair design with hanging attachment for storage

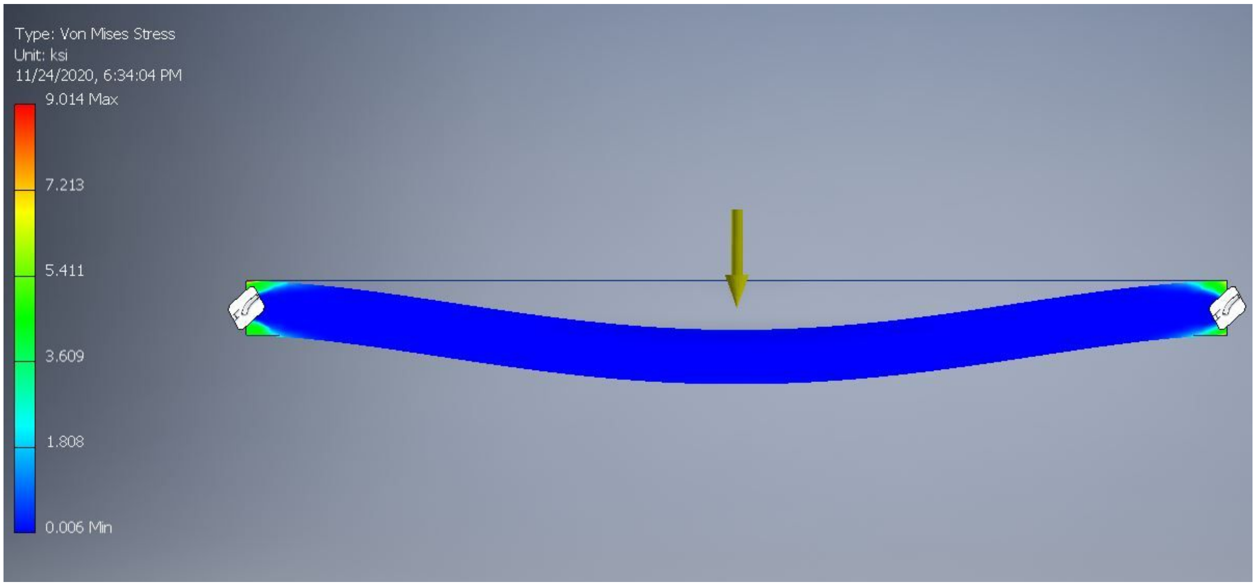


Figure B.14 ANSYS stress analysis for attachment full span shows maximum stress as 9.014 ksi

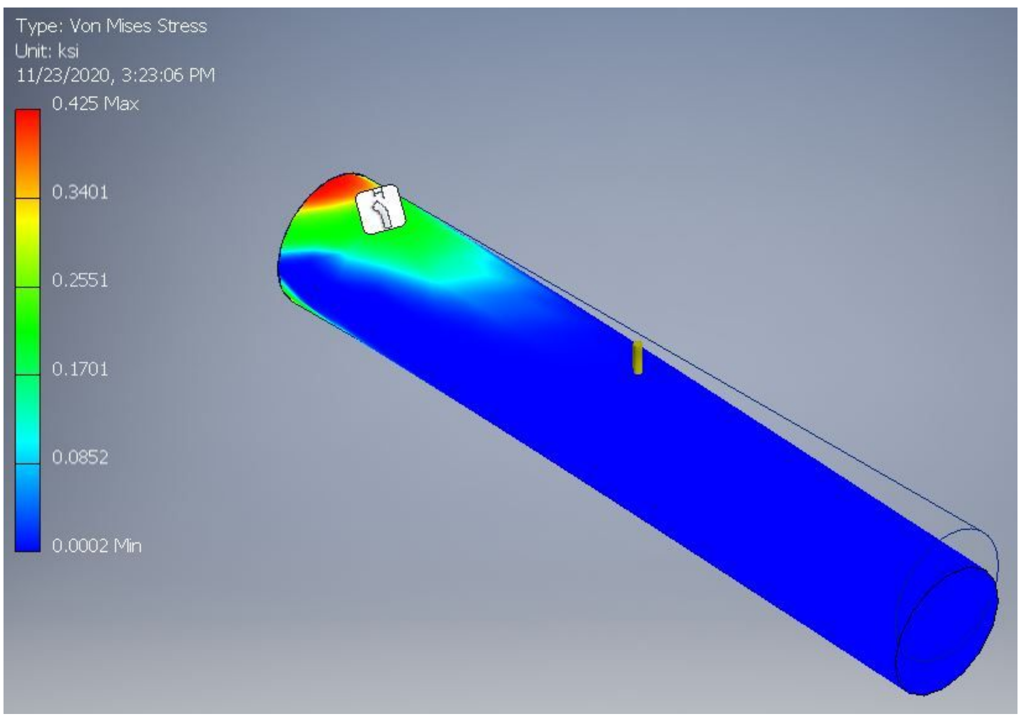


Figure B.15 ANSYS stress analysis for attachment partial span shows maximum stress as 0.425 ksi

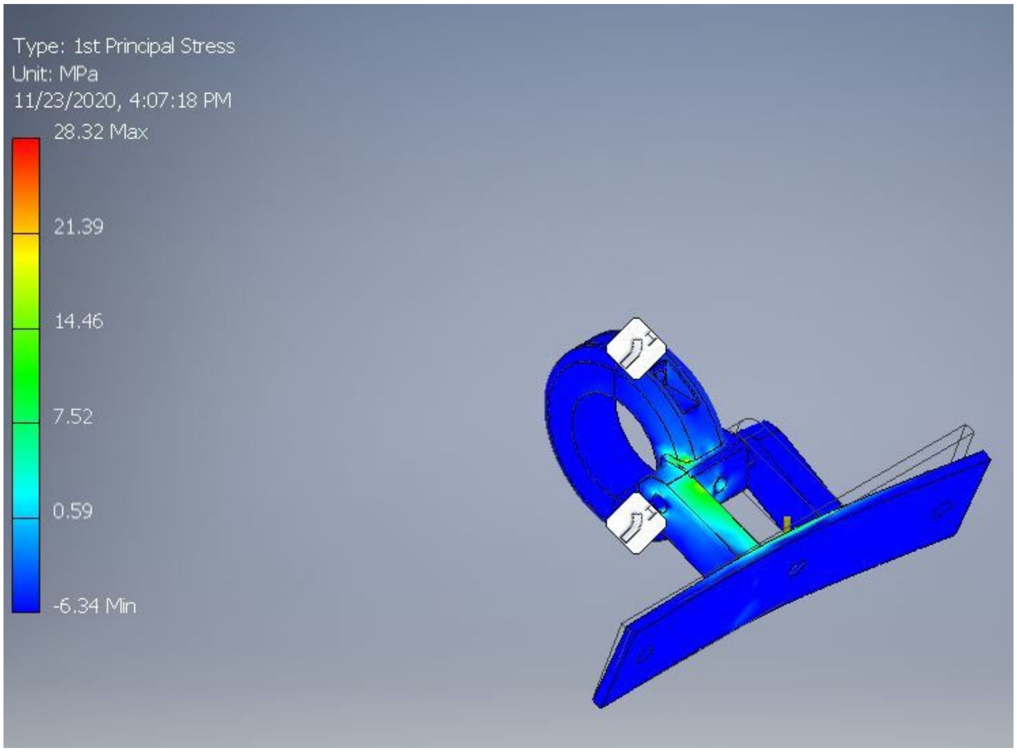


Figure B.16 ANSYS stress analysis for the hitch attachment shows maximum stress of 4.11 ksi

```
close all
clear all
clc
%Motor Horsepower Calculation
m = (198+25+36.7)/2.205/2; %kg, assuming two wheels in the back
mu = 0.9; %static friction coefficient, rubber on dry asphalt
grade1 = 4.76; %degrees
grade2 = 7.13; %degrees
g = 9.81; %m/s^2
r = [5 7.5 8 8.5 9 12]/2; %in, but will get same hp for any r
r= r./39.37; %m, wheel radius
v = 3.0/2.237; %m/s, translational velocity
omega = v./r; %rad/s, rotational velocity

Fp1 = mu*m*g*cosd(grade1)+m*g*sind(grade1); %N
Fp2 = mu*m*g*cosd(grade2)+m*g*sind(grade2); %N

Fp1 = m*g*sind(grade1); %no friction
Fp2 = m*g*sind(grade2); %no friction

T1 = Fp1.*r; %Nm
T2 = Fp2.*r; %Nm

P1 = T1.*omega/745.7; %hp (1 mechanical hp = 745.7 W)
P2 = T2(1).*omega(1)/745.7 %hp (1 mechanical hp = 745.7 W)
```

```
P2 =

    0.1290
```

Figure B.17 Motor horsepower calculations in MATLAB

```
clear all;
clc;


BV = 48;%Battery Voltage
BC = 10;%Battery capacity in amp-hours
MV = 32;%Motor voltage
MPH = 2;%Speed traveling Mph
wheelRad = 2.5; %in
GearRat = 1.38;
%1.38 for 48 volt
%2.69 for 32
MotorInput = [1,0.5]; %what percentage of torque is generated by motor
CircumWheel = 2*pi*wheelRad; %circumference of wheel
WheelRpm = ((MPH*63360)/60)/CircumWheel;  %converts Mph to RPM for calc
MotorRpm = WheelRpm * GearRat;
MotorRads = (MotorRpm*(2*pi))/60; %converts RPM to Rad/s for motor
MaxTorque = 3.86; %N-M
NoLoadSpd = 5760; %RPM
TScSlope = -(MaxTorque/NoLoadSpd); %slope of Torque speed curve
TorqueM = ((TScSlope * MotorRpm) + MaxTorque)*MotorInput; %motor torque needed to travel

MC = (2*((TorqueM*MotorRads)/BV));%Motor Current amps using 60% efficiency
maxDist = 4; %in miles
runTime = (maxDist/MPH)*3600; %in seconds
Power = ((MotorRpm*(2*pi)/60)*TorqueM)/0.6; %power generated at specific speed, in watts
BatEngC = runTime*Power; %joules of battery needed
AHN = 2*(BatEngC/(3600*BV)); %conversion from jouls to Amp-Hours
%multiplying AHN by 2 because using 2 motors

AmpHours = (MC*(runTime/3600))/0.6
%max weight added is 22 lbs
```

```
AmpHours =

   10.0813    5.0406
```

Figure B.18 Battery ampere hour calculations for chosen motor in MATLAB for running motor at 100% and 50%

distance calculations based on battery capacity

```
BV = 48;%Battery Voltage
BC = 10;%Battery capacity in amp-hours
MV = 32;%Motor voltage
MPH = 2;%Speed traveling Mph
wheelRad = 2.5; %in
GearRat = 1.38;
%1.38 for 48 volt
%2.69 for 32
MotorInput = [1, 0.5]; %what percentage of torque is generated by motor
CircumWheel = 2*pi*wheelRad; %circumference of wheel
WheelRpm = ((MPH*63360)/60)/CircumWheel;  %converts Mph to RPM for calc
MotorRpm = WheelRpm * GearRat;
MotorRads = (MotorRpm*(2*pi))/60; %converts RPM to Rad/s for motor
MaxTorque = 3.86; %N-M
NoLoadSpd = 5760; %RPM
TScSlope = -(MaxTorque/NoLoadSpd); %slope of Torque speed curve
TorqueM = ((TScSlope * MotorRpm) + MaxTorque)*MotorInput; %motor torque needed to travel

MC = (2*((TorqueM*MotorRads)/BV));%Motor Current amps using 60% efficiency
AHPM = MC/MPH; %calculate the amp hours per mile
Dist = BC./AHPM
```

```
Dist =

    6.6129   13.2258
```

Figure B.19 Distance calculations based on battery capacity for chosen motor in MATLAB for running motor at 100% and 50%

```
close all
clear all
clc

%Motor Horsepower Calculation
m = (198+25+36.7)/2.205/2; %kg, assuming two wheels in the back
mu = 0.9; %static friction coefficient, rubber on dry asphalt
grade1 = 4.76; %degrees
grade2 = 7.13; %degrees
g = 9.81; %m/s^2
r = 5/2; %radius of the wheel we purchased
r= r./39.37; %m, wheel radius
v = 2.25/2.237; %m/s, translational velocity
omega = v/r; %rad/s, rotational velocity


Fp2 = m*g*sind(grade2); %no friction


T2 = Fp2*r; %Nm


P2 = T2*omega/745.7; %hp (1 mechanical hp = 745.7 W)

%what we know
Tmotor = 3.86;
eff = 0.85;
Tout = T2;
wout = omega; %rad/s

Geff_T = Tout(1) / Tmotor(1)/ eff(1)
```

```
Geff_T =

    1.3878
```

Figure B.20 Gear ratio calculations in MATLAB

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

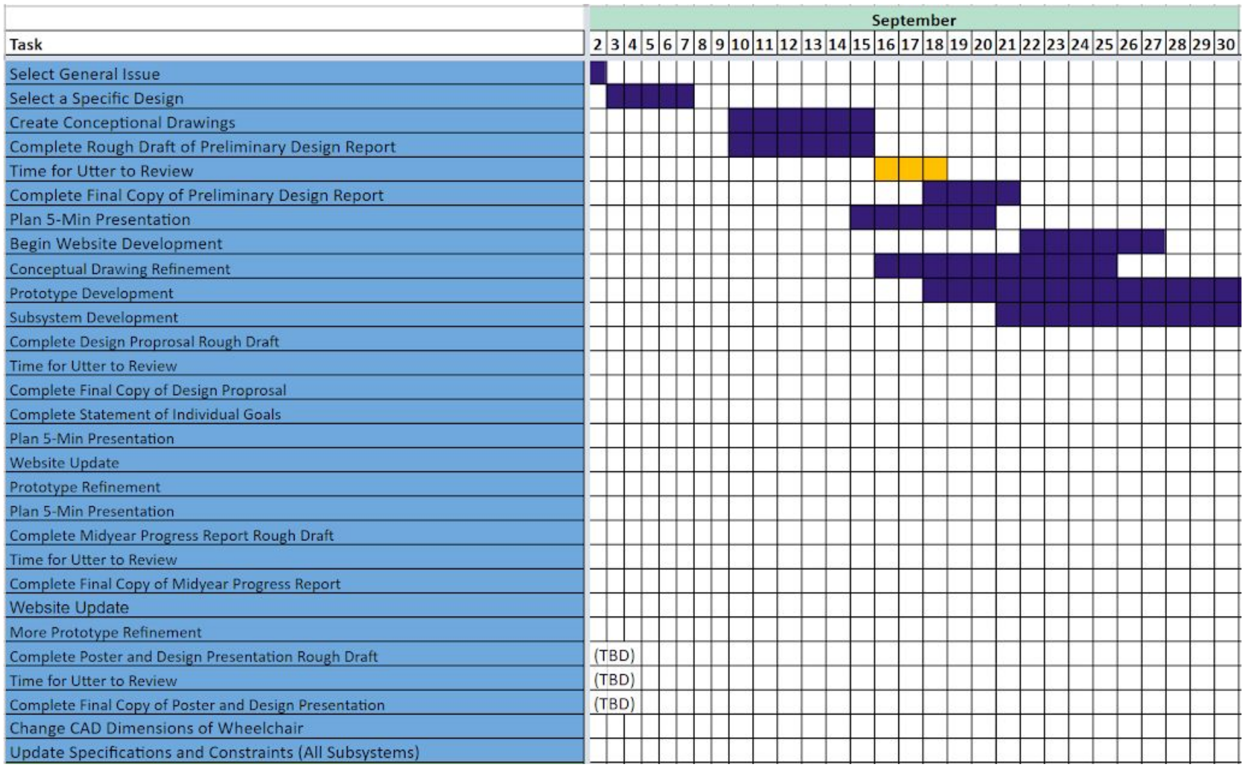
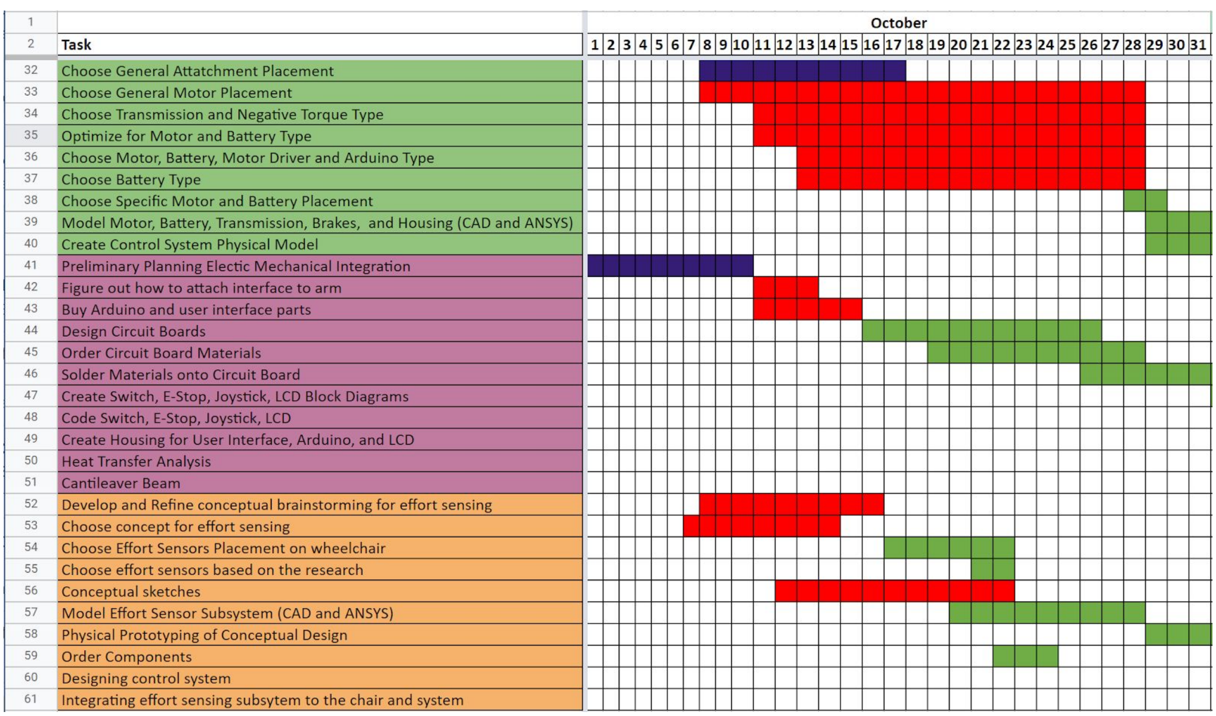


Table E.2: Semester Gantt Chart Tasks and timeline for the month of October for the subteams



******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)