LAFAYETTE COLLEGE

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

Wheelchair Team Prototype Specification Report

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1. Introduction

The purpose of the report is to describe the different specifications and functions for the entire wheelchair team and for each subsystem team. The general specifications cover the specifications that overlap among subsystems and testing methods for the full wheelchair device assembly. In addition to the general the subteam sections cover specifications that are specific to the functionality of the subsystem. The specifications identified in this report are derived from the design objectives, which have been informed by research on the largest areas of improvement for wheelchair users. 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. These complement design objectives that have developed over the school year. All specifications will be further developed as prototyping and modeling continue, but the current specifications are found in the sections below for the full team's general specifications and subteam specific specifications.

The report is organized into four sections below: the general specifications, propulsion team specifications, electro-mechanical integration team specifications, and effort sensing team specifications. Each section discusses functionality, including the general functionality and the subteam specific functionality. Following the brief overview of function, each section includes a specification table and an explanation of the specifications below.

2. General Specifications

The general function of the project is to make areas that are difficult to navigate more accessible to people with limited mobility by creating a device designed to assist manual wheelchair users in ascending and descending inclines and declines. The general specifications include cost, weight, waterproofing, width, and International Organization for Standardization (ISO) specifications and testing procedures. A lot of the specifications are based on the International Organization for Standardization standards for electric and manual wheelchairs ISO 7176. The ISO is a highly reputable organization for standards and is the source that will be used to ensure the entire device is safe and accessible for users. The general specifications incorporate aspects of the design and testing that overlap among subteams. This includes things such as waterproofing all subsystems (Specification G3) as well as other overlapping specifications. These overlapping specifications can be seen in the table below (Table 1).

Table 1 and the following tables have a distinction between target minimum value, target maximum value and constrained maximum/minimum value. This is to distinguish between the target values that the device is trying to achieve (Target maximum and minimum value) and the constrained max/min that would cause the device to violate a key function or ISO standard. The target values are intended to be met, but if they are not met a serious redesign may not be required. However, if a constrained value is not met, a redesign should be considered and discussed because the device is not meeting a previously agreed constraint. In addition to numerical values, the constrained values include answers such as "yes" and "no" to show if the specification must be met. The maximize/minimize/target/constraint column found in the table shows whether the target values should be maximized, minimized, meet a target value, or if the specification is constrained and must meet a value, standard, or function.

Table 1: General Design Specifications and Metrics

#	Metric/Specification	Target Minimum Value	Target Maximum Value	Unit	Maximize /Minimize/ Target/Constraint	Constrained Max/Min or Yes/No
G1	Total cost of device	0	$2,500	USD	Minimize	
G2	Total added weight of the device	0	25	lbs.	Minimize	
G3	Waterproofing all parts of the device				Constraint	Yes
G4	Maximum added width	0	4	in.	Minimize	
G5	Static stability full assembly testing				Costraint	Yes
G6	Dynamic stability full assembly testing				Constraint	Yes
G7	Brake effectiveness full assembly testing				Constraint	Yes
G8	Obstacle climbing ability full assembly testing				Constraint	Yes
G9	Power and control systems full assembly testing				Constraint	Yes
G10	Batteries and charges full assembly testing				Constraint	Yes

G1. Specification G1 involves the maximum total cost of the device. The device cost will not exceed $2500 to stay within competitive pricing of prior art (Table A1). This will put the device in the same price range as the Firefly 2.5 [5] and E-Motion [1] and significantly below the SmartDrive MX2 Power Assist [11], and the SMOOV One [9], all of which are existing motor assist devices on the market (Table A1, Appendix A). Cost of manufacturing, and cost of parts is always considered in determining the design of the device to ensure this specification is met.

G2. Specification G2 sets the total weight of the add-on device to a target maximum of 25 lbs. This means that the total weight of all the parts being added to the wheelchair should not exceed 25 lbs. Setting the total added weight to 25 lbs allows the user to push the wheelchair when the device is not in use and attached the device to the wheelchair with minimal added strain [2]. Similarly to Specification G1, Specification G2 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 A1 (Appendix A), 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). To achieve this specification, lightweight materials are being used where applicable such as aluminum while also balancing Specification G1 to keep costs low.

G3. This specification involves weatherproofing all parts of the device. To achieve this the device should withstand weather including snow, and rain based on ISO 7176-9 standards and testing methods [12]. 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. ISO 7176-9 specifies the requirements and test methods to determine the effects of different climatic events for electric wheelchairs [12]. Standard ISO 7176-9 will be used to test the device and assess the device's ability to withstand different weather changes (Specification G3). To aid in weatherproofing, the device's electrical components are being waterproofed and stainless steel and aluminum are the main materials used to deter corrosion and allow the device to operate in most outdoor environments.

G4. The added width of the device is defined as the width the device extends outward from the current width of the wheelchair. It should not exceed the specified value of 4 inches to allow the device and wheelchair to pass through an ADA regulated doorway [12]. Specification G4 is derived from the width of the standard manual wheelchair (26 inches) and the standard width of a doorway (36 inches) [12]. Adding a width of 4 inches at maximum (Specification G4) 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. To reduce added width of the design every component has been sized and positioned to fit within the original footprint of the wheelchair.

G5. Specification G5 is defined as the static stability testing method for the wheelchair with the device attached. Specification G5 ensures the device passes the static stability testing for wheelchairs set by the ISO under the standard ISO 7176-1 [12]. Both Specification G5 and G6 ensure that the device will not make the wheelchair unsafe while it is and is not moving. This testing will be carried out when the device prototype is fully assembled.

G6. This specification defines the testing method for dynamic stability as defined by ISO 7176-2 [12]. ISO 7176-2 sets the standards for determining dynamic stability of the wheelchair and is intended to be followed [12]. Testing Specification G6 using ISO 7176-2 requires a full assembly prototype of the device attached to a wheelchair. This specification will be taken into account during the testing stage of our design, which will occur after we complete our first prototype.

G7. Specification G7 defines the testing method for brake effectiveness as set by ISO-7176-3 [12]. Specification G7 focuses on safety and derives from ISO 7176-3, which specifies the test methods and effectiveness of brakes for manual and electric wheelchairs [12]. The current design allows for some electrical braking of the wheelchair from the add-on device which will be tested using the ISO 7176-3 standards once the prototype is assembled.

G8. Specification G8 constrains the device to the standards and testing method of ISO 7176-10 determining the obstacle-climbing ability of electrically powered wheelchairs [12]. Specification G8 is justified by ISO 7176-10 [12]. It specifies the test methods for determining the ability of the device and wheelchair to climb and descend obstacles [12]. This standard heavily covers the intended goal of the device. The testing as defined by ISO 7176-10 will be completed on a full assembly prototype.

G9. Specification G9 determines the requirements and testing method as set by ISO 7176-14 for the power and control system of electric wheelchairs, and it states the maximum speed of the wheelchair, 9.32 mph [12]. This constraint will be used to confirm that the device's control and power system meet the requirements of the standard. The maximum speed will be handled by the precision of the speed being controlled by the Electro-Mechanical Integration Team. This also overlaps with Specification P4 below for the propulsion team which ensures the propulsion system does not violate ISO 7176-6 which will limit the maximum speed of an electric wheelchair. This testing will be conducted on the full assembly prototype.

G10. The wheelchair design must not violate the ISO 7176-25 requirements for batteries and chargers [12]. This requirement defines that for lead acid batteries and chargers, the rated input voltage should be no greater than 250 Vac and the nominal output voltage should be no greater than 36V. Specification G10 ensures that the device's batteries meet the requirements of this standard. This was taken into account when choosing the battery. We have currently chosen a 48V lithium ion battery. While this goes over the nominal voltage, this is not a lead acid battery, which is the one specified in this ISO requirement. This standard also defines the testing method for batteries and battery chargers intended for use with electrically powered wheelchairs [12]. These testing methods will be used to test the full assembly prototype and ensure the batteries and chargers are safe and up to ISO standards. ISO 7176-31 is a standard under development concerning lithium based battery technology for electric wheelchairs. If this is published before the completion of the project, it may be used to further define this specification.

3. Propulsion Team Specifications

The Propulsion Team is in charge of the following functions of the device: to be able to propel, slow down, turn, and stop a user in a wheelchair on level ground, inclines, and declines. Below is a list of metrics and specifications used by the Propulsion Team when designing the device. These are based on both knowledge of prior arts, and research of speeds of wheelchair users and people who do not regularly use wheelchairs. Note that all speeds in the table below are being calculated based on the average weight of an American man, 198 lbs [9]. This is a conservative design choice because the weight of an average American man is greater than the average weight of an American,

Table 2: Propulsion Team Specifications and Metrics

#	Metric/Specification	Target Minimum Value	Target Maximum Value	Unit	Maximize /Minimize /Target/ Constraint	Constrained Max/Min or Yes/No
P1	Range of device on full battery with no user effort	1.5	∞	Miles	Maximize	
P2	Range of device on full battery with 50% user effort	12	∞	Miles	Maximize	
P3	Safely Tranversible grade of incline/decline	8.3	∞	% grade	Maximize	
P4	Maximum possible speed on level ground, incline and decline			mph	Constraint	9.32
P5	Unassisted speed on level ground	3		mph	Maximize	
P6	Unassisted speed on a incline	2.25		mph	Maximize	

#	Metric/Specification	Target Minimum Value	Target Maximum Value	Unit	Maximize /Minimize /Target/ Constraint	Constrained Max/Min or Yes/No
P7	Unassisted speed on a decline	3		mpd	Maximize	
P8	Curb height device can overcome	6		in	Maximize	
P9	Grade incline or decline on which the device can stop without user intervention	5		% grade	Maximize	
P10	Ability to go backwards				Constraint	Yes
P11	Ability to steer				Constraint	Yes
P12	Limited resistance				Constraint	Yes

P1. The range of the device on a full battery with no user effort is the allowable distance the user can travel with the device with 0% effort input from the user until the battery runs out of charge. The value of 1.5 miles was chosen based on the average distance an American walks in a day, which was determined to be around 1.5 to 2 miles per day [8]. This distance was used when determining the necessary amp hours of the battery, and it was used to determine the distance the battery of the device should be able to accomplish with no user effort (Specification P3).

P2. The range of the device on a full battery with 50% effort from the user is the allowable distance the user can travel with the device with effort input from the user 50% of the time, until the battery runs out of charge. This range of 12 miles was chosen because it is comparable and competitive to other prior art (Table A1). 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. This value was used when determining the necessary amp hours of the battery.

P3. Specification P3 defines the grade of the incline or decline our device should be able to safely traverse. It was created based on the maximum grade of "hand-propelled wheelchair ramps," which is 8.3%. The maximum grade for an electric wheelchair is 12.5%. At minimum, the device needs to be able to allow the user to navigate the maximum ramp built for a manual wheelchair. However, the grade at which the device can operate will be maximized to help the user navigate steeper inclines and declines [13]. The maximum grade was used to determine the necessary motor horsepower.

P4. The maximum possible speed of the device on level ground, an incline or a decline, is the maximum speed of the user when the device is in use, which includes any input from the user. Specification P4 is based on the International Organization for Standardization (ISO) Standard 7176-6, which states that the maximum speed for electric wheelchairs is 9.32 mph (15 km/hr) [12]. This has not been used in any of our current calculations; however, in accordance with the ISO standard, when testing and using the prototype, it will not push the wheelchair at a speed exceeding 9.32 mph.

P5. The unassisted achievable speed is defined as the speed the motor is able to propel the user without any user assistance. It is the lower bound of the maximum speed achievable by the device and controller with no user input for acceleration or deceleration. On flat ground, the user should be able to travel 3.0 mph without any user input [9]. This value was chosen because it is the average walking speed of an adult [3]. This is used to ensure the user is at a safe speed, but not too slow to keep pace with additional foot traffic. This specification was taken into consideration when choosing the motor horsepower.

P6. The unassisted achievable speed on an incline is defined as the speed the motor is able to propel the user without any user assistance on an 8.3-12.5% grade, as defined in Specification P5. It is the lower bound of the maximum speed achievable by the device and controller with no user input for acceleration or deceleration. The unassisted achievable speed of the user on an 8.3%-12.5% grade incline should be 2.25 mph with . This is the speed of the user without any user input. The value was chosen based on the average speed of a person who uses a manual wheelchair [6]. 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. This specification was taken into consideration when choosing the motor horsepower.

P7. The unassisted achievable speed on a decline is defined as the speed the motor is able to propel the user without any user assistance on an 8.3-12.5% grade, as defined in Specification P5. This is the speed of the user without any user input. This value was determined by using the average walking speed of an adult [3]. This is used to ensure the user is at a safe speed, but not too slow to keep pace with additional foot traffic. This unassisted achievable speed was used for the maximum grade decline (Specification P3) to keep the user within the same safe operating level but this speed can be increased or decreased based on the user's comfort. As with Specification P6 and P7, this value was used when calculating the motor horsepower.

P8. The curb height the device can overcome is the maximum curb the device will be able to go over. The device should be able to overcome a 6 inch curb or bump in the road. The device should be able to overcome inconsistencies in the road to allow for greater accessibility and use on different surfaces and roads. A 6 in curb is the standard curb height, so the device should be able to allow the device and wheelchair to overcome this without overextending the spring or putting too much added strain on the user [7]. This maximum curb height was used when determining what spring we should use. Our spring will be able to extend the correct amount to allow the device to overcome a 6 in curb.

P9. The device should be able to stop the wheelchair and the user on a 5% grade decline or incline. The maximum grade of most pedestrian facilities and public access routes is limited to a 5% grade at maximum[7]. For this reason the device should be able to fully stop on a 5% grade decline or decline. To put the stopping capabilities within the competitive range of other products on the market the current target incline grade is 8.3% for stopping without user intervention. No user intervention means that the person using the wheelchair would not have to aid in stopping by gripping the wheels or using the wheelchairs built in braking mechanism. An extension spring mechanism is the current mechanism in place to allow the device to break using the motors of the add-on device. The spring ensures a normal force at the point of contact going forwards and backwards. Static analysis was done to design a spring that would allow the device to stop on an 8.3% grade but changes to the spring strength may change to balance Specification P8, P9, and P10.

P10. The device is able to go backwards on level ground, which means the user will be able to propel the wheelchair backwards without the use of their hands on the wheels of the wheelchair. The ability to go backwards was chosen due to safety concerns regarding the user's hands on the wheels while also being propelled by the device, and because it increases the accessibility of the wheelchair and device. Using static calculations on an inclined plane the device is able to come to a complete stop without user input so with the addition of the spring the device should be able to go backwards on level ground as well. Going backwards on an incline or decline may also be possible but may add additional safety concerns so should be addressed further at a later point in time.

P11. The device is capable of steering on level ground, inclines and declines, which means the user should not have to use their hands on wheels of the wheelchair to complete a turn. The ability to steer was chosen due to concern regarding the safety of the user's hands on the wheel of the wheelchair while being propelled by our device. To achieve this, the propulsion system includes two identical housings and motors that can operate independently at different speeds and control steering of the user to some extent. The extent of the turning radius and other specifications relating to steering have not yet been determined.

P12. Limited resistance is defined as reducing the effort of the user to overcome any resistive force added by the device. There are two moments we've considered that would cause extra strain on them. First, when the user does not want assistance, the device would be in “off mode”; however, this would cause the user to have to turn the wheel of the device, which is connected to the motor. When not on, the motor has resistance, so the user would be feeling this resistance. To reduce the extra effort by the user, strain gauges are being added to measure the propulsive force. When in “off mode” the motor’s speed will be adjusted to turn with the user, but not give any assistance in forward or backward movement. Lastly, when making turns the device might also cause resistance due to there being no freedom of movement in the lateral direction of the device. This resistance when making turns, or any lateral movement, is being resolved by the chosen Rotacaster wheels. These wheels are multi-directional because they have smaller parts that allow lateral movement of the wheels.

4. Electro-Mechanical Integration Specifications

The goal of the Electro-Mechanical Integration team is to create a user-friendly interface that allows the wheelchair user to control the system. This includes control over whether the system is automatic, semi-automatic, or manual as well as altering the speed and direction of the wheelchair in automatic mode and the assistance level in semi-automatic mode. There will also be an LCD screen that allows the user to check the battery level, speed, effort level, and which mode their wheelchair is in.

Table 3: Electro-Mechanical Integration Team Specification and Metrics

#	Metric/Specification	Minimum Value	Maximum Value	Unit	Maximize /Minimize/ Target/ Constraint	Constrained Max/Min
E1	User have control over the speed in automatic mode	-0.2	0.2	mph	Target	Necessary
E2	User have control level of assistance in semi-automatic mode	-2	2	%	Target	Necessary
E3	System should not overheat		104	°F	Minimize	302
E4	Ability to quickly disable electronics and motors					Necessary

E1. If the wheelchair is in automatic mode, the user should be able to adjust the speed of the wheelchair. The accuracy of the speed read from the potentiometer should be ± 0.2 mph. The user must feel comfortable in the wheelchair and the way in which it is performing.

E2. The user will change the amount of assistance desired in semi-automatic mode by a potentiometer on the interface housing. The user should be able to be within ± 2% of the desired effort level in order to ensure the user is comfortable using the wheelchair.

E3. Fans are being used to remove the heat inside the housing from the electrical components. The system should not overheat and damage any of the internal electrical components. At 104°F , the user may be uncomfortable touching the interface, defeating its purpose, and at 302°F, the interface itself will begin to melt.

E4. An emergency stop button will be on the side of the interface housing for the user to press in the case of an emergency. Pressing this button will stop all electronic components and the running motor. The emergency stop returns the wheelchair to its manual mode.

5. Effort Sensing Specifications

The goal of the effort sensing team is to take the measurements necessary to determine the effort input by the user. The system must be able to distinguish between user applied forces and system applied forces to ensure the mathematical model has the information to determine the output force that needs to be applied based on those different inputs. This ensures the effort sensing system can provide accurately calculated output to communicate the input to the other subsystems. The specifications below relate to the timeliness and accuracy of these measurements. For all sensor sampling rate constraints, further development is required to determine appropriate sampling rates. The specific metrics for sampling rates are unknown, but these rates should be maximized.

Table 4: Effort Sensing Team Specification and Metrics

#	Metric/Specification	Minimum Value	Maximum Value	Unit	Maximize /Minimize/ Target/Constraint	Constrained Max/Min
ES1	Sampling rate of 9DOF measurement system		∞		Maximize	
ES2	Sampling rate of strain gauge measurement system		∞		Maximize	
ES3	Response time to call to the propulsion system	0			Minimize	Necessary
ES4	Response time to register user input from user to the joystick	0			Minimize	Necessary
ES5	Percent error in angle measurement	0			Minimize	
ES6	Percent error in strain measurement	0			Minimize	
ES7	Cost	0			Minimize	

ES1. The sampling rate of the 9 degree of freedom, or 9DOF, measurement system must be fast enough to ensure data is collected quickly enough for the system to provide an output for the angle and orientation of the chair in space. This ensures the 9DOF measurement system can provide timely output to communicate the input to the other subsystems.

ES2. The sampling rate of the strain gauge measurement system must be fast enough to ensure data is collected quickly enough for the system to provide an output for the force of the wheel add-on on the chair. This ensures the strain gauge measurement system can provide timely output to communicate the input to the other subsystems.

ES3. The response time to call the propulsion system must be fast enough to ensure the propulsion system can make adjustments based on input to operate efficiently. This ensures the propulsion system can use the data to respond as designed.

ES4. The response time of registering user input from the joystick must be fast enough to ensure the 9DOF measurement system can correctly implement the mathematical model based on the input to efficiently generate output. This ensures the effort sensing subsystem will be able to generate outputs quickly based on the input from the electro-mechanical integration subsystem.

ES5. The percent error in the angle measurement of the wheelchair must be minimized to ensure the 9DOF measurement system's mathematical model can produce outputs accurately.

ES6. The percent error in the strain measurement of the wheelchair must be minimized to ensure the strain gauge measurement system's force calculation is accurate and can be correctly imputed into the other 9DOF measurement system.

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Appendix A: Background Research and Prior Art

Table A1: Pricing, Weights, Range and Speeds of Different Wheelchair Add-On Devices currently on the market

	SmartDrive MX2 Power Assist [10]	**Firefly 2.5 [5]**	**E-Motion [1]**	**SMOOV One [9]**
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