University of Illinois at Urbana-Champaign

ECE445
Design Document

Project: Motor-Aided Wheelchair

Group 26

TA: Yichi Zhang

Jiacheng Huang, Guangxun Zhai, Zilin Zhao
jh59, gzhai5, zilinz2

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Contents

1 Introduction

1.1 Objectives

An accurate epidemiological data on the use of wheelchairs is hard to obtain, but an estimation states that around 1% of the world's population, or about 65 million people, are living with a disability needing a wheelchair. The United States has an estimated 3.3 million wheelchair users, and the number is increasing each year. In Canada, there are approximately 288,800 wheelchair and scooter users aged 15 and over, about 1% of the Canadian population. The actual number of wheelchair users might be even greater, given the fact that the above data includes only manual wheelchair users instead of those in residences or long-term care facilities. Data given by the EU statistical office Eurostatin claims that there are an estimated 5 million wheelchair users in Europe. However, in 2003 it was estimated that 20 million of those who needed a wheelchair to get around did not have one, and of those who did, very few had a wheelchair adequate to meet their needs. [1]

Our goal is to develop a motorized wheelchair to help pushers. Instead of being controlled only by the person sitting in through a panel on the wheelchair, our wheelchair detects the force exerted by the pusher and gives an assistive force to make it easy to push. The assistive force is calculated by a smooth function to give the pusher an intuitive and fluent experience.

1.2 Background

Nowadays, motorized wheelchairs are becoming more widespread, but there remain people with disabilities that need more care who are not able to control the motorized wheelchairs themselves. In such situations, an ordinary motorized wheelchair controlled by the person sitting in is unlikely to help, given the fact that the medical personnel or family members who push the wheelchair could not be benefited. Therefore, developing a motor-aided wheelchair that gives feedback assistive power to the wheels makes people easier to push.

2 High-level Requirements

- When accelerating the wheelchair, people who push the chair are just required to use $1/(k+1)$ of the original force to push, saving much effort. Because during this process, the motor will provide k times the pushing force (F_{in}) to supply for the rest of the force that is required for the movement of the wheelchair.
- If the wheelchair is passing the speed limit, which is 1.5 m/s, there's no need for the chair pusher to use great power to drag back. Instead, the motor will automatically provide $F_{motor} = -F_{in}$ while spinning in the opposite direction to slow down the wheels until the speed is below the limit.
- For safety concerns, the person sitting in the chair is able to use the control panel to immediately halt the wheelchair with deceleration of -1.5 m/s^2. This feature has the highest priority, allowing the user to have a method to stop the wheel on his own at any time. .

3 Design

The external force from the handle is detected by force sensors implemented into the handle. Depending on how large the force is, the motor will provide extra power to the wheels to aid the movement of the wheelchair. There is also a control panel installed on the wheelchair to order immediate stop of the wheelchair for emergencies.

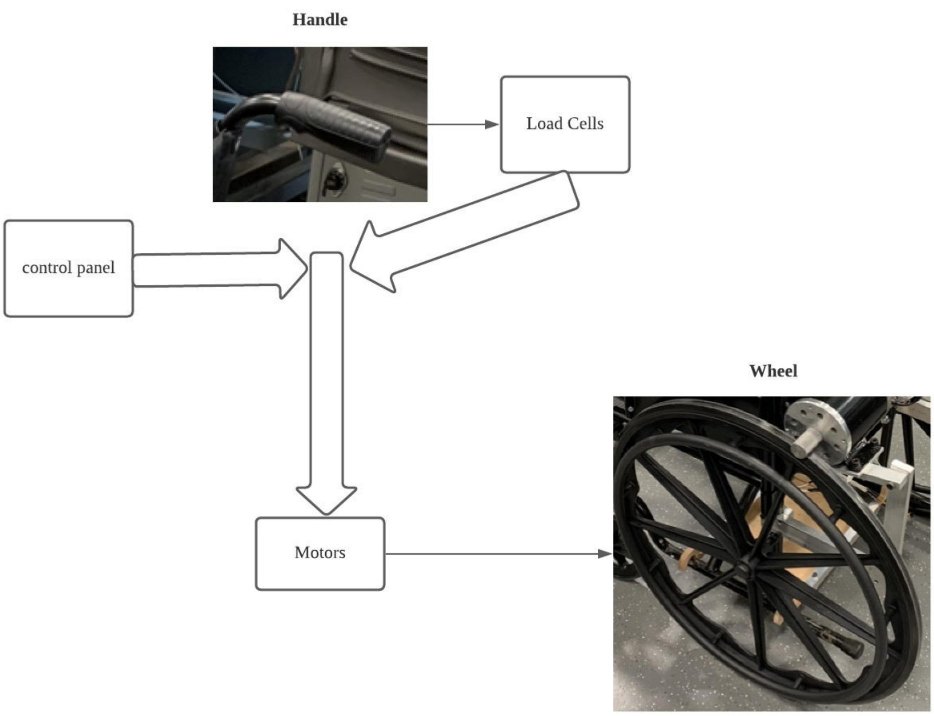


Figure 1: Visual Solution of Motor-aided wheelchair

3.1 Block Diagram

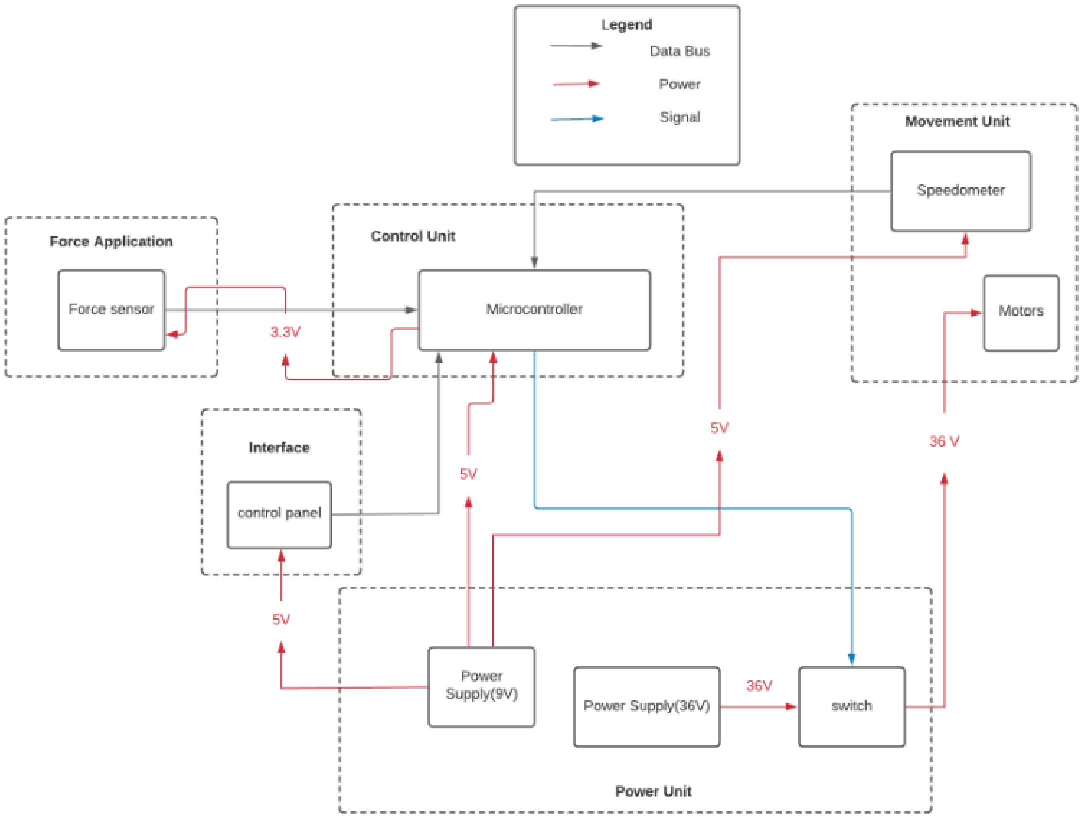


Figure 2: Block Diagram of Motor-Aided Wheelchair

4 Subsystems

4.1 Force Application

The force application unit is where our main input, push force, generates. The load cell we are going to use is FX292X-100A-0025-L, which has a scale range of 25lbf. When we push or pull the wheelchair, the force exerts on the handle will be detected by the implemented force sensors. force sensors will be generating corresponding singles to the microcontroller. [1]

Requirements	Verification
1. A handle joint that will be able to move forward 0.5 cm based on the push. 2. Force cells are able to detect the magnitude of the force exerted and give electrical signals to the microcontroller.	1. Move the handle forward. Handle should reset to the middle if no force is applied. 2. Move the handle forward with force measurement. Read the signal from the force sensor to see if the data is accurate (mostly to judge whether there is a linear relationship between the force that we push the chair and the data).

4.2 Interface

A control panel is provided for the person sitting in the wheelchair with stop command stop. The stop command on the control panel has the highest priority for safety concern, so that the person sitting in the wheelchair is able to stop it immediately. Deceleration will be set to -1.5 m/s^2 until the wheel stops spinning. Since the maximum speed is 1.5 m/s, it will take a maximum of 1s to stop the wheelchair after the stop command. This time period allows the momentum of the person sitting on the wheelchair to decrease so that he or she will not fall off.

Requirements	Verification
1. A button that sends the stop signal to the microcontroller. 2. The stop signal has the highest priority.	1. Check the computer monitor on the microcontroller for the signal input when pressing the button. 2. Move the wheelchair with all sorts of movement with motors on and press the button to see if the wheelchair stops in every situation.

4.3 Control Unit

The smooth function is implemented into the microcontroller. Based on force detection, achieved by force sensors implemented in handles, the motor will provide corresponding extra power to the wheels to give the person who is pushing the wheelchair an extra help. The whole point of this function is to determine how much the extra force should be applied to the motor. Since we have corresponding motors related to corresponding force sensors, we do not need to distinguish the motion status of the wheelchair. Instead, the power motor provides to the wheel is solely depending on how much force is exerted on the force sensor. The motor will always, under safe circumstances, provide k (now k = 4) times the power detected on the force sensor. However, if the acceleration is detected to be too large, the motor will provide a negative force which is equal to the force detected by the force sensor to limit the movement of the wheelchair. In order to do so, the microcontroller outputs a PWM signal to switch the 36 V power supply on and off to control the overall average power.

Requirements	Verification
1. The microcontroller needs to track the signal from sensors. 2. The microcontroller should be able to output PWM signals. 3. Average voltage of the PWM signals should be 6 volts to 36 volts.	1. Program the microcontroller in DEBUG mode first, and choose some pins to output data from the sensor to test if input is received correctly. 2. In DEBUG mode, measure the output of the corresponding pin to determine whether it is correct.

4.4 Power Supply

Our power supply has an input voltage of 36 volts and 9 volts[4]. 9V is then regulated to 5 volts and 3.3 volts, as needed by the microcontroller and sensors. To do so, we determine to use two regulators, the first one with an input of 9 volts and a fixed output of 5 volts, and the second one with an input of 5 volts and a fixed output of 3.3 volts.

Requirements	Verification
1. Able to output a voltage of 36 V 2. Able to output a voltage of 9 V 3. The battery needs to be rechargeable.	1. Measure the voltage between the power supply using a multimeter and ensure the date is 36V the error difference is less than 0.1V. 2. Measure the voltage between the power supply using a multimeter and ensure the data is 9V the error difference is less than 0.1V. 3. Recharge the battery for several times and ensure the voltages between the battery still keeps around 36V and 9V.

4.5 Movement Unit

The power adapter receives 36 volts from the power supply, and is told by the microcontroller how much of the power should be distributed to the motors. The power on the motors determines the spinning speed of the motor and the velocity of the wheels. The motor could control itself to spin either clockwise or counterclockwise according to the different situations. More specifically, when we would like the wheelchair doing an acceleration movement, the motor should spin clockwise to generate a force moving frontwards. And when we want to stop or accelerate the wheelchair, we will look for a negative force on the wheel, which is counterclockwise.

For safety concerns, we set a maximum speed (1.5m/s) for the wheelchair. In order to monitor the speed, we include a velocity receiver (moving coil) in the movement unit. Whenever the speed observed from the sensor exceeds the limit, the microcontroller will send a signal to the motor to control it to spin counterclockwise, thus generating a negative force to keep the wheelchair in safe speed range.

Requirements	Verification
1. The voltage outputs 36 volts. 2. The motors should be able to drive the wheelchair at 1.5 m/s.	1. Measure the voltage across the power supply. 2. When the moving speed of a wheelchair approaches 1.5m/s, we could witness a counterclockwise spin of the motor and the final speed should not exceed 1.5m/s.

5 Smooth Function

One of the most important parts of our project is the smooth function, which takes F_{in}, the input force from human's hands on the handle and the data is collected by the force sensor. The output of our function V_{motor} is the final voltage that should be applied across the motor.

Since our design is a motor-aided wheelchair, most of the time the movement of the chair is still largely controlled by our hands, and what our circuit does is to save some human effort and ensure the safety of pushing forward the wheelchair. The output power is given by the formula: $P_{motor} = k \cdot F_{in} \cdot v_{wheel}$, which could also be written as $F_{motor} = k \cdot F_{in}$. "k" is a constant number that we define as number 4 and write into the microcontroller code ahead of time.

The situation that our smooth function is going to solve has 4 basic states shown in the figures shown below.

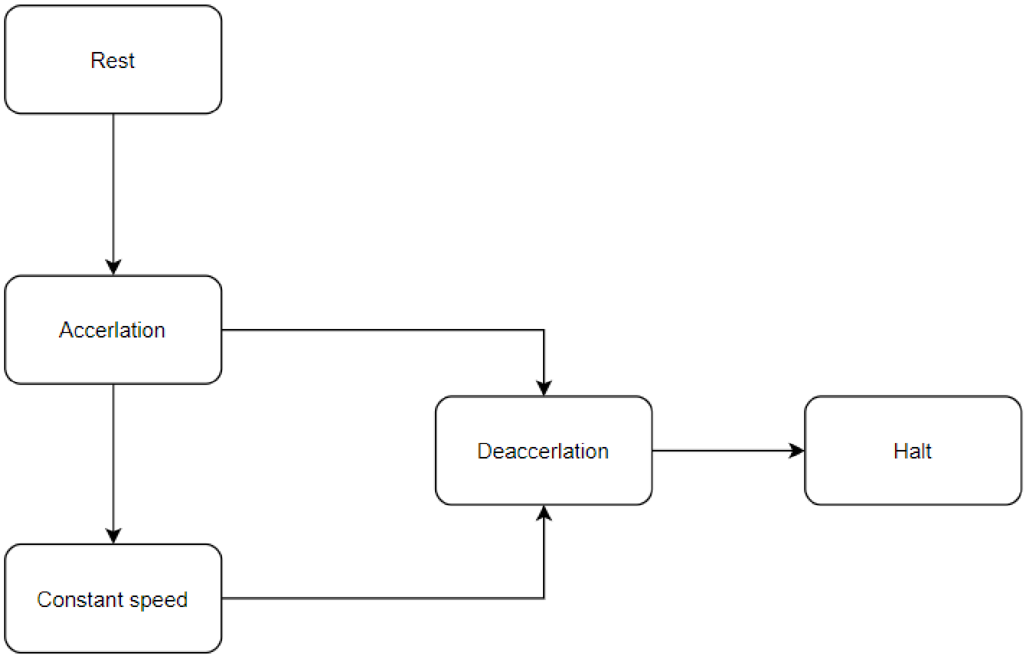
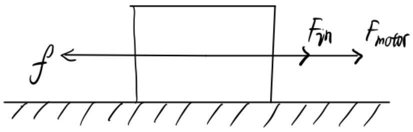


Figure 3: Flowchart for the Smooth Function

During the rest and halt states, the velocity of the wheelchair is zero, and there is no horizontal force on the chair. The second state is an acceleration state since when we want to start pushing, the wheels will always increase its speed first. The velocity in this state is positive and below the limit, and the F_{net} is pointing to the direction of movement. When the acceleration makes the speed exceed 1.5m/s, the motor will change its direction and give a force which is equalled to the Fin but has the opposite direction. Thus, the total force in the direction of moving forward will be cancelled out and the net force will only remain the friction point opposite to the movement direction, thus making the wheelchair accelerate to control the speed. There is also an ideal state called "constant speed" between "acceleration" and "deceleration". This state is a theoretical one because it is hard to just use pushing to control the pushing force Fin to enter a perfect balance that a = 0. Most of the time, the wheelchair will be in the states of "acceleration" and "deceleration" within the speed limit.

f is almost a fixed number on the same floor.

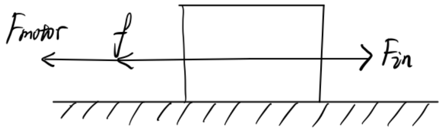


$F_{motor} = k \cdot F_{in} \quad (k=4)$

$\nearrow$ Rest / halt : $f = F_{in} + F_{motor} = (k+1) F_{in}$

$\searrow$ Acceleration : $F_{net} = F_{in} + F_{motor} - f > 0$

$= (k+1) F_{in} - f > 0 \Rightarrow a_{net} > 0$



$F_{motor} = k \cdot F_{in} \quad (k=-1) \longrightarrow$ Deacceleration :

$F_{motor} = -F_{in}$

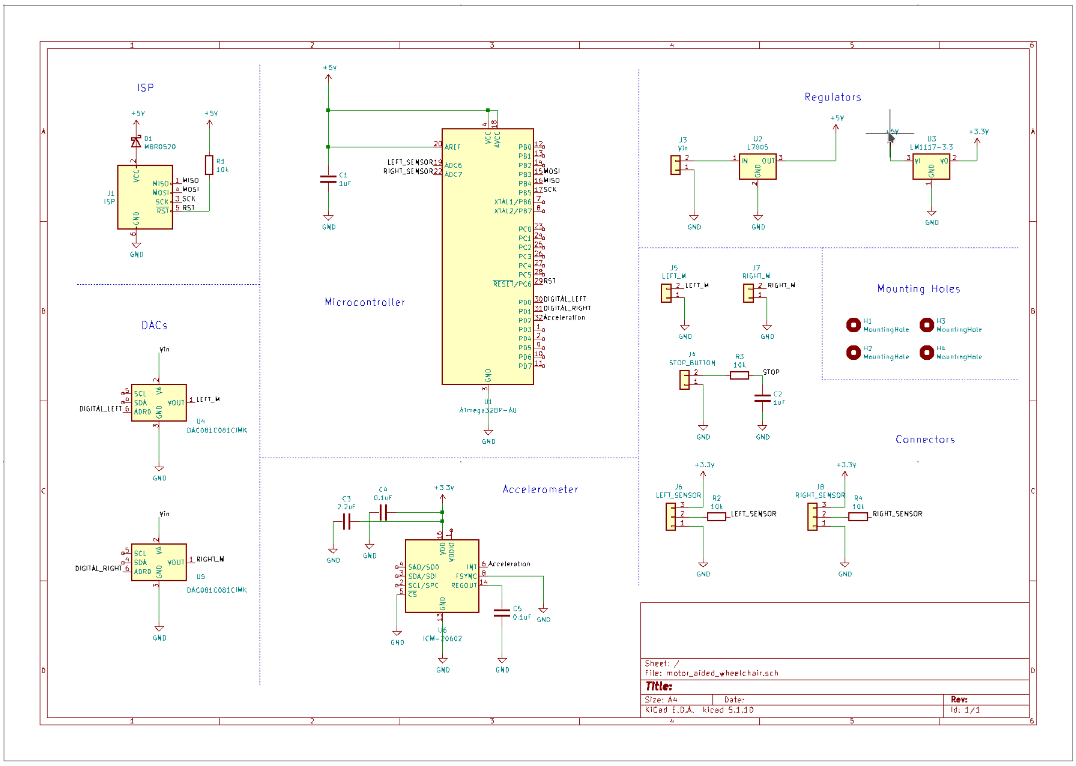
$F_{net} = F_{in} + F_{motor} - f$

$= F_{in} - F_{in} - f$

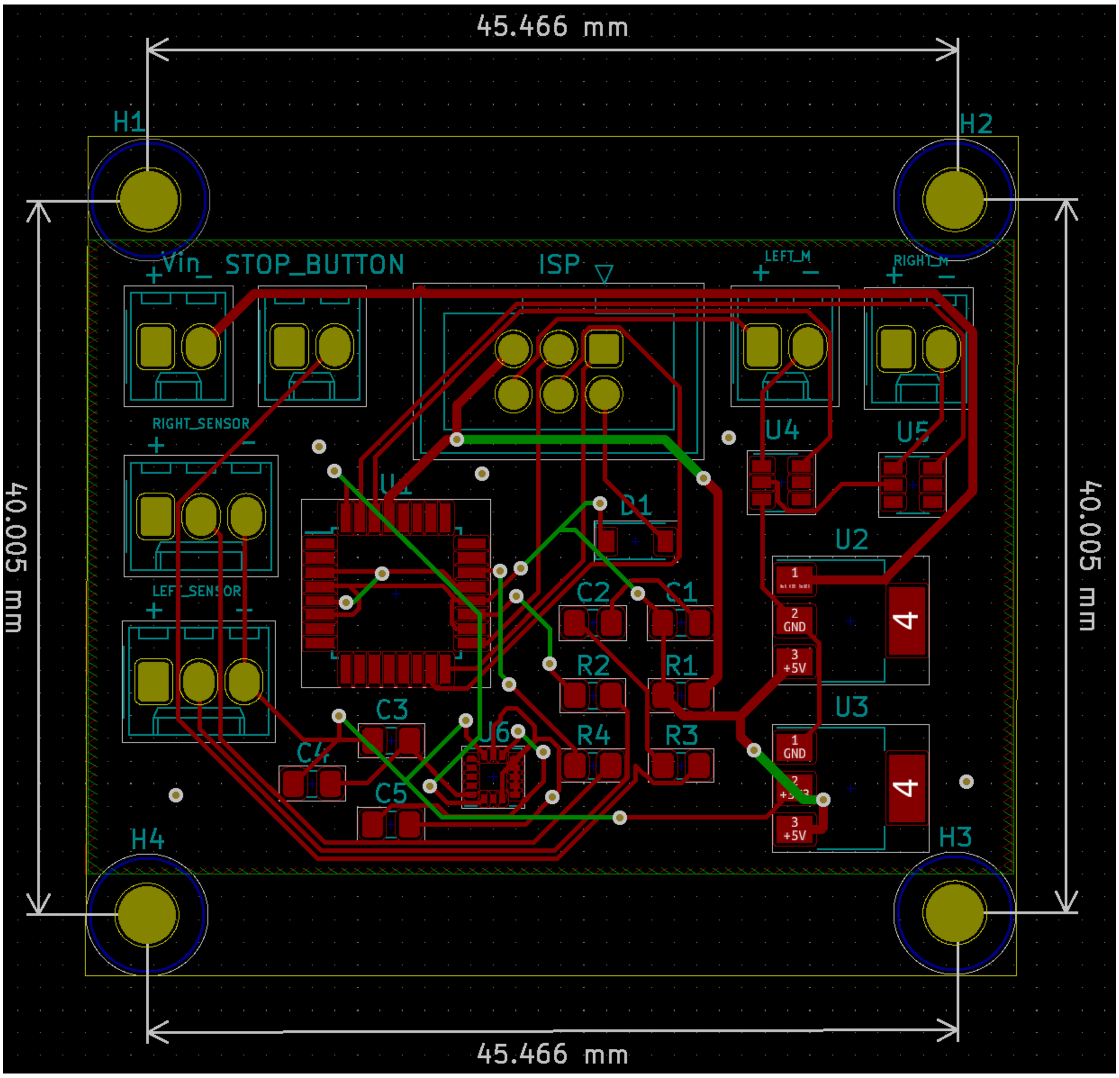
$= -f < 0 \Rightarrow a_{net} < 0$

Figure 4: Concept States of the Smooth Function

6 Schematics



7 PCB Layout



45.466 mm
H1
H2
Vin
STOP_BUTTON
ISP
LEFT_M
RIGHT_M
RIGHT_SENSOR
LEFT_SENSOR
U1
U2
U3
U4
U5
U6
D1
C1
C2
C3
C4
C5
R1
R2
R3
R4
GND
+5V
H4
H3
40.005 mm
40.005 mm
45.466 mm

8 Costs

Our hourly salary is 30$/hour. We work 15 hours per week. We have three team members. Our labor fee is:

$$30\$/hour \cdot 2.5 \cdot 15hours/week \cdot 16weeks \cdot 3members = 54000\$$$

Part	Manufacturer	Quantity	Cost/Unit	Total
Wheelchair		1	none	none
Motor		2	none	none
force sensors	Amazon	4	6$	24$
Microcontroller(ATmega328P)	Microchip	1	4$	4$
Assorted resistors, capacitors, ICs, crystals, sockets	Digikey			10$
PCB	PCBWay	10	2$	20$
Machine Shop service			none	none
				58$

9 Schedule

Week	Zilin Zhao	Jiacheng Huang	Guangxun Zhai
9/27/21	Finish up design document	Finish PCB schematic and routing	Collet data relating to wheelchair movement
10/04/21	Implement and test smooth function	Prepare for first round PCB order	Develop force analysis diagram for wheelchair with motors
10/11/21	Finish smooth function with input from force sensors and output to power regulator	Testing limit cases including maximum speed, acceleration, and breaking.	Test force sensors and power regulator
10/18/21	Solder and test first version of PCB	Connect and calibrate PCB with motors	Design version 2 PCB schematic and routing
10/25/21	Implement smooth function into PCB and testing	Finish second round PCB order	Design handles with force sensors and talk to machine shop
11/01/21	Design and implement control panel	Test smooth function performance on different surface and weight load with extreme cases	Implement handle design and test flexibility
11/08/21	Solder and test second version of PCB	Optimize smooth function and wire connection	Integrate the electrical and physical parts of wheelchair
11/15/21	Mock demo and debug	Mock demo and debug	Mock demo and debug
11/22/21	Fall break	Fall break	Fall break
11/29/21	Begin final report/demonstration	Begin final report/demonstration	Begin final report/demonstration
12/06/21	Finish final report/presentation	Finish final report/presentation	Finish final report/presentation

10 Tolerance Analysis

The power supply of this project is one obstacle, because we need to power the wheelchair for a relatively long time, and powering such a wheelchair plus a person sitting in it is an exhausting job. Making sure that the energy stored is enough is a challenge. The coefficient of friction of the wheels to the ground is around 0.3 to 0.7. Assuming the coefficient is equal to 0.5, then the force needed to drive the wheelchair while a person sitting in is $0.5 * 150kg * 10m/s^2 = 750N$. Then the power needed to drive the wheelchair in the maximum speed limit is $750N * 1.5m/s = 1125W$. For an hour, the battery needs to store $1125W * 3600s = 4050kJ$. Fortunately, this result is still reasonable. Plus the fact that the wheelchair is only delivering the most power at the start of pushing, this energy could be reduced a large amount.

Another special case we need to take in consideration is when the push force or speed of wheels pass the limit. In this case, ideally, we want motors to apply a negative direction power to wheels to make the speed limit to 1.5m/s. Normally, we have motors applying 4 times the power from the push force. However, when the speed is off limit, we have

$$P_{extra} = P_{motor}$$

where P_{extra} is the extra power from the push force that makes the speed go off limit and P_{motor} is the power from the motor while they are in the opposite direction. For this case, we will also try to establish an extreme case test where we will find out how much power will the motor spinning slide with the wheel. We will not include this extreme case into our consideration though since normally we do not push the wheelchair that hard.

11 Ethics and Safety

Since our project is a motor-aided wheelchair, we will definitely include patients' safety into our consideration. The relationship between patients' safety and motors' power will be a tricky problem to deal with. If the acceleration is too large, it will cause some serious danger to the patients. Also, according to the IEEE Code of Ethics [5], we do not want to damage the surrounding area, so that the function that determines how much power we allow to the motor will be carefully dealt with. Motors involved in this project require relatively high voltage and current, which might cause injuries to people doing experiments. However, with caution, we are confident to reduce the chance of such danger as much as possible by limiting the power at the beginning of the experiment. In addition to that, we can lift the wheelchair up so that the wheels do not touch the ground.

Our smooth function will include a lot of complicated cases. When testing maximum speed, there are multiple steps testing the speed, which will have the potential for the wheelchair to go off the limit and damage the environment. Potential emergency breakpoints will be included in the algorithm to stop the motor if anything off the limit happens. Also, besides the case where motor will provide negative power to wheels when input force signal is larger than limit, motors will also be instructed to stop or provide negative power to wheels if wheels's speed is larger than limit. This detection can be down within the algorithm since motors are directly in touch with wheels.

Power supply above 40 V will have the potential danger to the human body. Since we have such powerful motors and the wheelchair is a moveable object, being cautious with power supply will be necessary. An important feature we will be using in this case is the voltage regulator. Since we will be using a voltage regulator in this case, we can connect the voltage regulator directly to the power supply before connecting it to the PCB and insulating the power supply into a sealed box. This setup will be better considering safety issues with large voltage. After we are done with the experiment and all the settings, we can then connect the voltage regulator to the PCB for the entire setup.

12 Citation

[1] Load Cells: Types, How It Works, Applications, & Advantages. (n.d.). Retrieved September 16, 2021, from https://www.encardio.com/blog/load-cells-types-how-it-works-applications-advantages/.

[2] Smooth rotation. (n.d.). Retrieved September 14, 2021, from https://www.machinedesign.com/archive/article/21812530/smooth-rotation.

[3]Power supply problem for 2 wheel drive robot. (n.d.). Retrieved September 14, 2021, from https://forum.arduino.cc/t/power-supply-problem-for-2-wheel-drive-robot/330397.

[4]IEEE - IEEE Code of Ethics. (n.d.). Retrieved September 14, 2021, from https://www.ieee.org/about/corporate/governance/p7-8.html.

[5]IEEE - IEEE Code of Ethics. (n.d.). Retrieved September 14, 2021, from IEEE Code of Ethics