
Glove Based
WheelChair Navigation

Team 40 - ECE445
Design Document
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1. Introduction

1.1 Problem and Solution Overview

Individuals with disabilities like paralysis or cerebral palsy find it hard to navigate a wheelchair using a joystick on the arm of the chair, considering limited hand control and movement. This is the inspiration to create a pair of gloves which can facilitate the maneuvering of the wheelchair with limited arm movement. The device (i.e. pair of gloves) would consist of two hand gloves; one with flex sensors to control the acceleration and speed of the motors. This is not accounting for the direction. We utilize an inertial measurement unit (IMU) in order to allow the user to accurately control the direction of the wheelchair, forward, back, left and right. The data from the sensors is fed into a microcontroller which transmits the information of motion and acceleration/deceleration to the motors (glove is wired to the chair). We will have one PCB that will encompass the data from the two sensors and relay the information to the motors. We will implement certain bandwidth filters that won't allow faulty data, essentially a threshold to make sure readings are appropriate. There will also be an emergency fail safe switch that decelerates and stops the wheelchair if needed.

The importance of the solution taps into the user base of individuals with nervous system diseases that can impair mobility (including cerebral palsy, multiple sclerosis, and Parkinson disease) or those facing musculoskeletal disorders. We derived the initial idea because one of our uncles suffered from major paralysis and he cannot really lift his arm which is the standard manner of controlling a wheelchair. This really restricted his independence, freedom and mobility which sparked the idea of how we can create a method to control a wheelchair with less effort. Our device aims at a means to help these individuals by allowing them to maneuver a wheelchair through gloves in a stable stationary position.

There is a plethora of companies attempting to create devices which can help perform daily tasks they otherwise could not do on their own such as the NeoMano wearable robotic glove. ‘With the NeoMano, patients and others with limited hand mobility can hold a cup of coffee, grip and twist a doorknob, use a toothbrush or comb, manipulate shirt buttons and zippers, and perform other basic tasks, enabling them to more fully participate in social activities [1]’. Our solution proposes a similar though specific platform to prompt movement independence. Another implementation proposed by Jigmee Machangpaa and Tejbanta Chingtham [2] uses accelerometer sensor, gyroscope sensor, ultrasonic sensor, relay, battery, DC stepper motor and raspberry pi. Our solution requires only three major sensors and would result in a cheaper device for the common user.

1.2 Visual Aid

Left arm: The user utilizes his/her fingers, by bending them, to control the speed of the wheelchair. Arm with open fingers means zero power to the motors (0 mph) while arm with a closed fist is the maximum speed (7 mph).

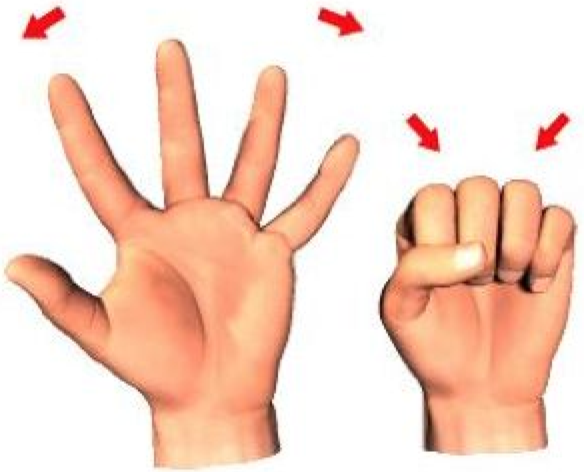

Figure 1: Left Arm Glove Guide (Flex Sensors)

Right arm: The user utilizes the stationary tilt of the arm to guide the direction of the wheelchair (front, back, right and left). The degree of turn is proportional to the degree of tilt in either direction.

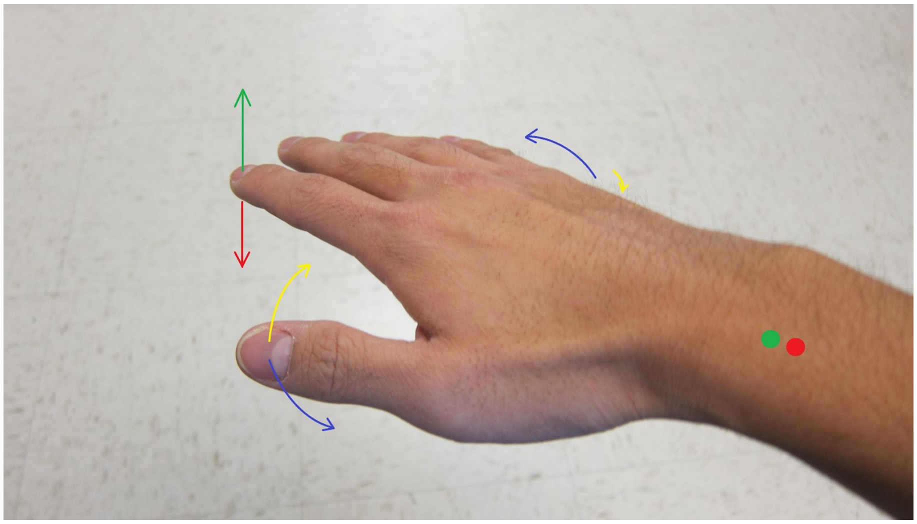

Figure 2: Right Arm Glove Guide (IMU) [5]

1.3 High-Level Requirements List

- Using the gloves, the user must be able to control the direction the wheelchair moves in (front, back, left, right) and also control the speed and angle of direction within a certain threshold of error (~10%).

- Latency time: There must not be more than 0.15s of latency between the user's movement and the interpreted command, to allow for lag-free navigation of the wheelchair.

- Emergency Response: Once the emergency button is pressed, the wheelchair must decelerate and come to a stop within 1s. If there are extreme readings recorded by the software module consistently for over 3s, then too the wheelchair must decelerate and come to a stop.

2. Design

2.1 Block Diagram

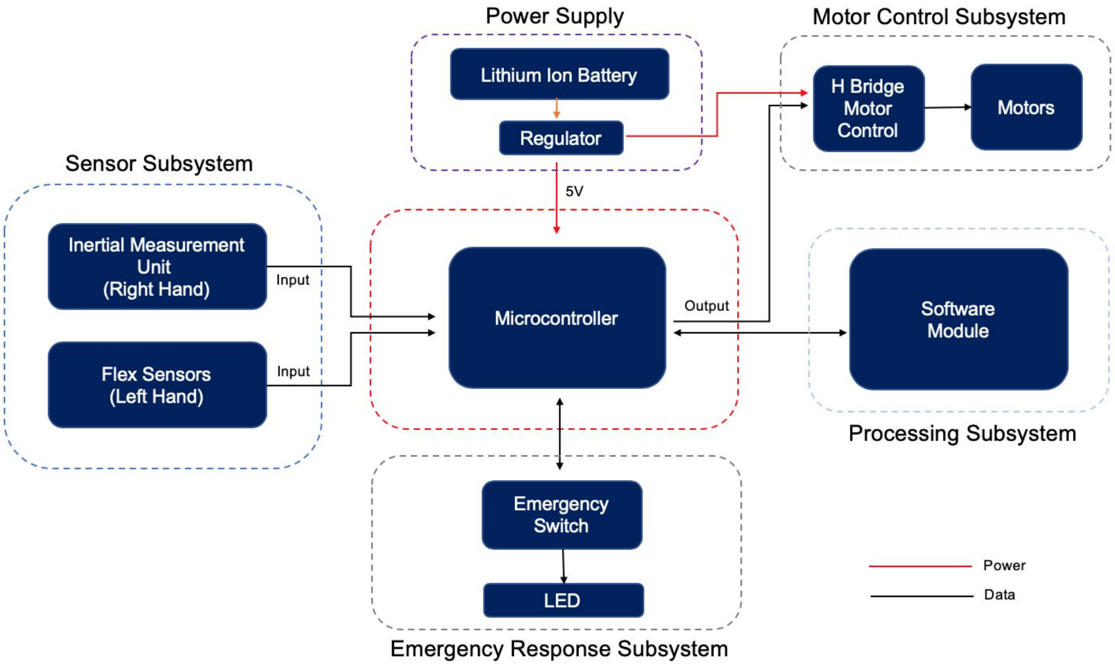

Figure 3: Block Diagram

2.2 Physical Design

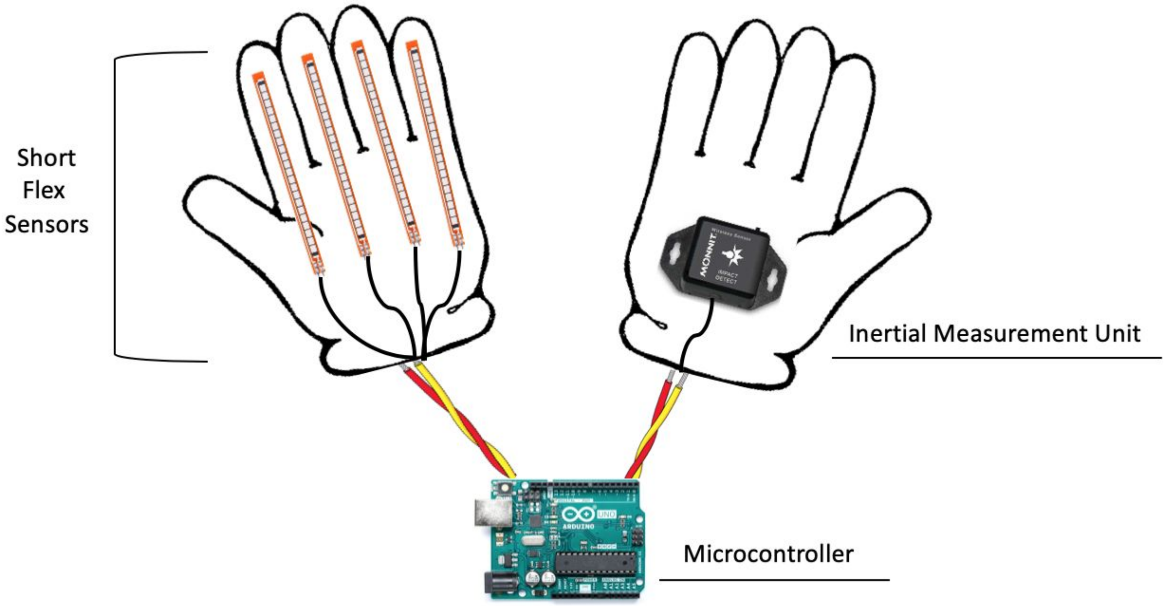

Figure 4: Physical Design

The physical component of our system involves two gloves. The left glove will have flex sensors attached along the fingers. This will help in detecting the bending of the fingers and clenching of the fist to change speeds. The left hand glove will have an Inertial Measurement Unit (IMU) attached to it to detect tilt movements of the hand for direction detection. Wires from these sensors will go into the microcontroller which will be placed on top of a motorized toy car. This motorized toy car essentially acts as a representation of a wheelchair.

2.3 Subsystems

The functionality of the device follows a sequence of events starting with the user's hand movement through the gloves. On the left hand, the flex sensors measure the pressure applied by folding of the fingers and on the right hand, the accelerometer detects left, right, forward and backward movements of the hand. Both of these then relay to the microcontroller which draws power from the lithium ion battery with an input voltage of ~5V and communicates the information to the software module.

The software module is designed to intake the sensor data, process it while removing extreme outliers and with a margin of error of 5% and transmit the information back to the microcontroller. The microcontroller then controls the motors of the wheelchair and guides the maneuvering accordingly. In the case of extreme movement of the arm, that would constitute an emergency and bring the wheelchair to a stop within 1s. Similarly, if needed, the user can press the emergency switch button. This will light up the LED next to the button and transmit the information to the microcontroller which will decelerate and stop the wheelchair.

2.3.1 Sensor Subsystem

The Sensor Subsystem primarily consists of two kinds of sensors - the flex sensor (SEN-10264 Flex Sensor) and an Inertial Measurement Unit (LSM9DS1 IMU). A flex sensor is a sensor that detects bending movement - the resistance across the sensor will increase when the sensor is flexed. There will be 4 flex sensors attached to the four fingers of the left-hand glove, which will send data regarding the extent of bending of the fingers to the microcontroller. To measure the tilt of the hand, we have an IMU attached to the right-hand glove. An IMU typically consists of an accelerometer, a gyroscope and a magnetometer. The accelerometer detects acceleration in all three directions - x,y and z - while the gyroscope detects the angle about the axis. Using data from these two sensors, we will detect the orientation of the right palm.

Requirements	Verification
1. The direction that the palm is oriented in should be the direction that the wheelchair takes. (There are 8 possible directions - forward, backward, right, left, front & right, front & left, back & right, back & left)	A) Hook up the IMU to the Microcontroller and fix it on the right palm. Attach a wheel to observe the direction it takes. B) Orient palm in a particular fashion and collect the sensor readings. C) Match up the sensor data with the direction that the wheel orients in. D) Over multiple iterations of this experiment, the wheel should orient correctly (over 90% to be accepted)
2. The flex sensors should offer minimum resistance when flat, and approximately 2x times this resistance when bent completely to 180 degrees.	A) Connect a flex sensor to a digital multimeter in the resistance mode. B) Check that the flat resistance corresponds to the value given in the

	datasheet with a tolerance of 5% deviation from that value. C) Bend the flex sensor to 180 degrees and measure resistance again. Verify that the values are within the given range.

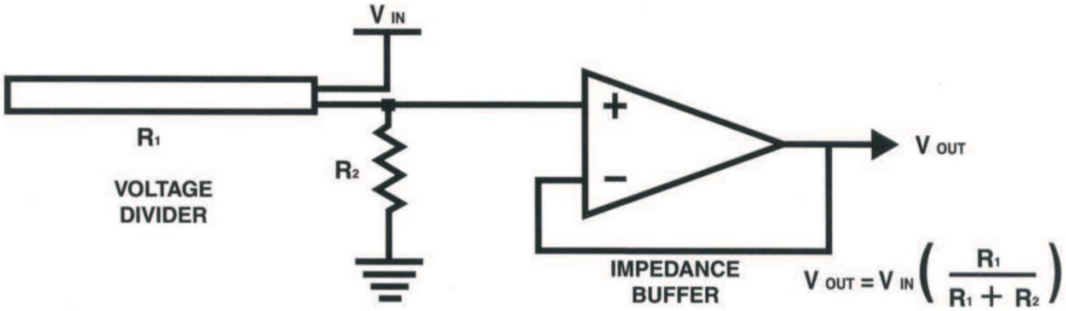

Figure 5: Flex Sensor Circuit Design [6]

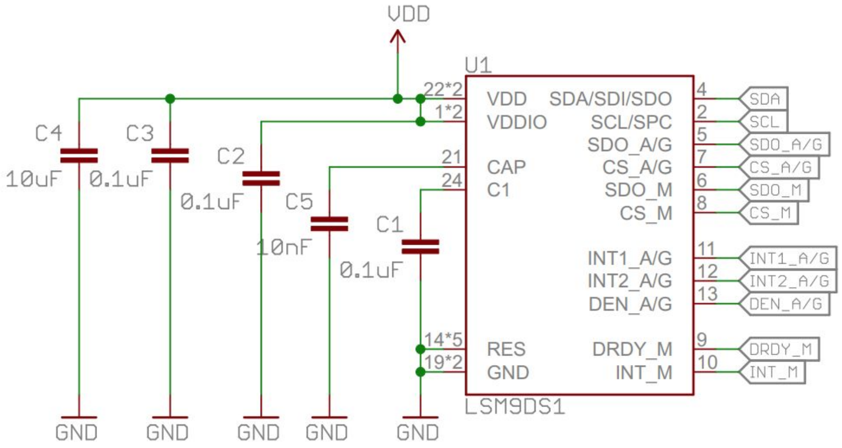

Figure 6: IMU LSM9DS1 Schematics [7]

2.3.2 Power Subsystem

The power subsystem contains two rechargeable Lithium Ion Polymer Batteries (Adafruit - PID 1317) which provide a consistent output of 8.4V when fully charged and sinks down to 7.4V. The capacity of each battery lies at 150 mAh. The built in safety circuitry of the battery keeps the voltage from going too high as well as being overused by cutting off the voltage at 3.0V when the battery dies. A Micro Lipo Charger will be used, as advised in the documentation, to get the battery fully charged consistent with the safety guidelines of the battery.

Power subsystem also incorporates a 5V 250 mA Linear Voltage Regulator (L4931-5.0 TO-92) which has a very low dropout voltage - measure to be approximately 0.4V. This means that to give a clean output voltage of 5V, the input needs to be at least 5.4V which we can achieve by our battery set. This combination of the battery and the voltage regulator will be used to power our microcontroller and motor.

Requirements	Verification
1. The voltage of the Lithium Ion Polymer batteries should be consistently in the range of 7.4V and 8.4V	A) Completely charge the battery using the Micro Lipo Charger. Hook up the batteries to a voltmeter to confirm that the battery system provides 8.35V - 8.45V. B) Discharge the batteries and check the voltmeter readings again. If it lies in the range of 7.35V - 7.45V, we can verify our battery system to be faultless.
2. Linear voltage regulator provides 5V with 2% regulation and an output current up to a peak of 300 mA.	A) We will use a DC power supply of 7V and with a current capacity of 300 mA as our input. Given the acceptable parameters of the regulator, the output from the voltage regulator should range between 4.9V - 5.1V which can be verified using a voltmeter.

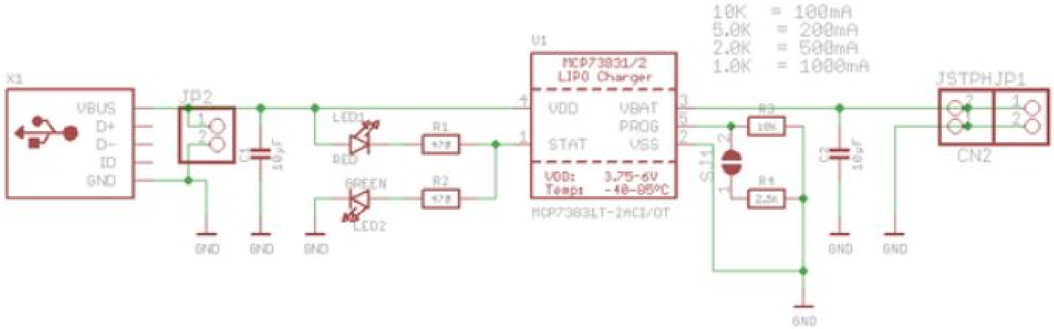

Figure 7: Lithium Ion Battery Schematics [8]

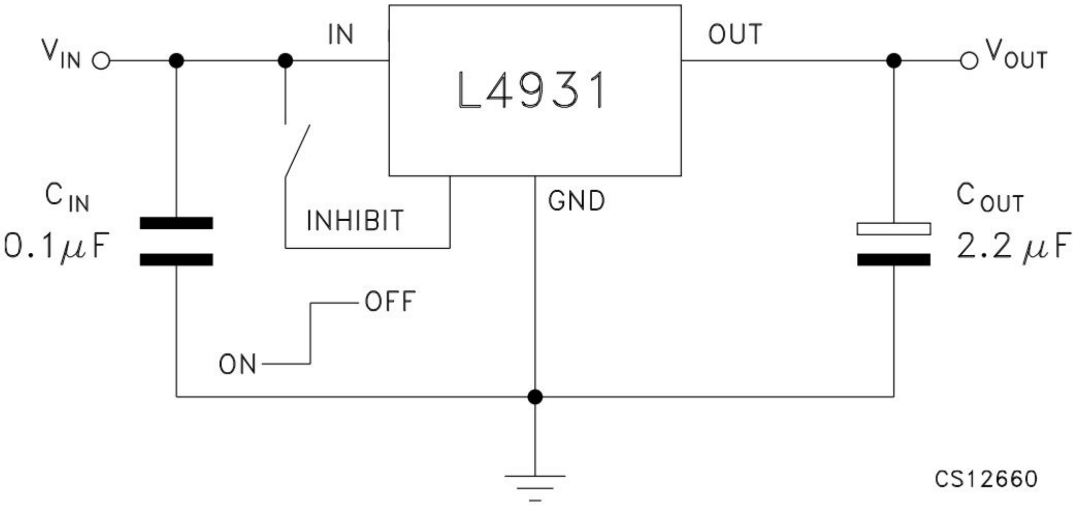

Figure 8: Linear Voltage Regulator Test Circuit [9]

2.3.3 Control Subsystem

For the Microcontroller, we will be using the ATMega328P which is a single-chip microcontroller based on the RISC architecture. It will collect data from the flex sensors as well as the IMU using the I2C serial protocol. The AVR ICSP Programming Adaptor will enable us to program the microcontroller.

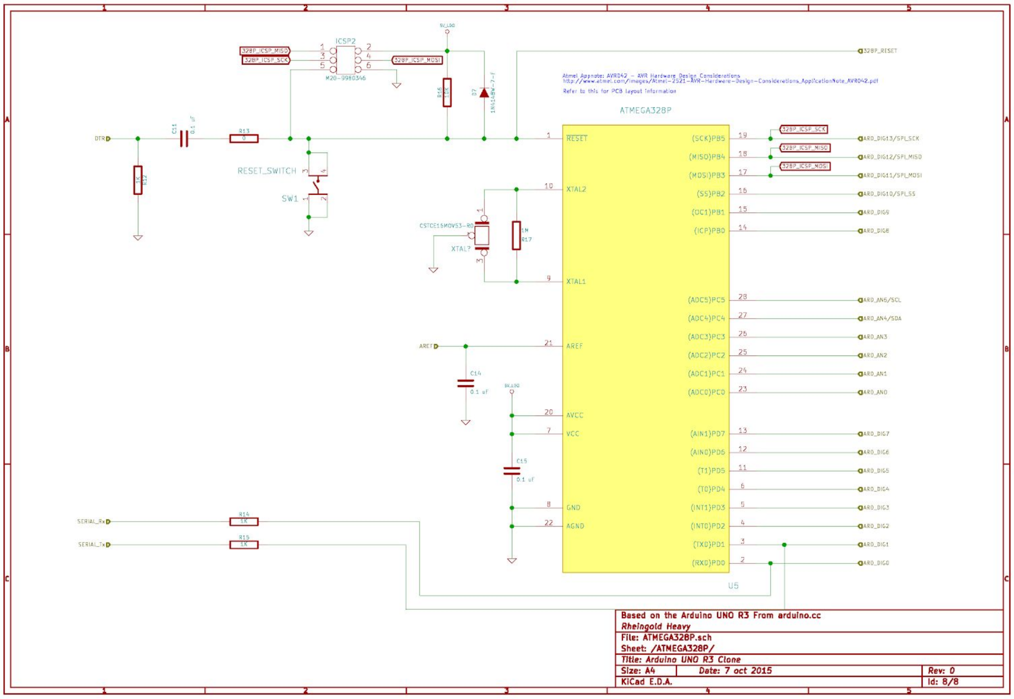

Figure 9: ATMEGA-328P Schematic [3]

Requirements	Verification
1. The control subsystem processes sensor data, computes the commands and sends output signals to motors within 1ms.	A) Hook up the system as required, with the sensors connected to the microcontroller. B) Give a directional command by tilting the palm in the desired direction. C) Use a software package to gather information about the time between the incoming command and the relaying of the instruction to the motor drivers. D) Ensure that this recorded time is less than 1ms. Average the difference over multiple iterations and ensure that this requirement is met over 85% of the time.
2. The microcontroller samples the sensors at a frequency of at least 100 Hz (every 10 ms).	A) Generate a waveform from the data received by any one of the sensors by

	B) Verify that a minimum of 100 data points are sampled every second by the microcontroller.

2.3.4 Processing Subsystem

The inputs to the processing subsystem are the values from the Microcontroller. The sensor signals will then be processed and run through various algorithms to conclude a desired action. The data from the flex sensors should essentially translate into how fast the motors are running. We will code up a band-pass filter that will ensure that the speeds are within reasonable range. In case the system identifies the analysed data to be out of safe bounds, it will send an emergency signal, causing the motors to stop.

Requirements	Verification
1. The motor speeds must be within the 0mph to 7mph range. Speeds greater than 7mph must be correctly identified as dangerous/out of bounds and emergency response should be initiated	A) Generate speeds that are less than 0mph and greater than 7mph using the output of the motor modulated by the flex sensors. B) Measure the output speed of the processing system based on the algorithm. C) Verify that all recorded speeds are between the 0mph-7mph range and speeds out of this range are appropriately cut-off by the algorithm.
2. The gyroscope outputs should be classified into the 8 directional markers (forward, backward, right, left, front & right, front & left, back & right, back & left) with an error margin of < 10%.	A) Orient the palm in the 8 specified directions and observe the output of the processing system. B) The analysed data should correctly match with the input orientation (if the palm was intended to be tilted forward, the analysed command

	should read forward). C) Run the test a minimum of 20 times and keep track of the errors with respect to wrong detection by the subsystem. D) Calculate the average error percentage and verify it to be less than 10%

2.3.5 Emergency Response Subsystem

The emergency response subsystem is essentially a push-button switch (Adafruit - PID 3870) system to cut the power to the motor when pressed. Another feature is that there will be an automatic cut-off of power if the voltage values are detected to go above/ beyond certain thresholds from the sensor. An LED (Adafruit 5mm LED - PID 299) light to indicate that the emergency response has been triggered and the motors will come to a stop within ~1s.

Requirement	Verification
1. The wheelchair must decelerate and come to a stop within 1s when the emergency switch is pressed	A) Manually initialize the push button and count the time taken from the instance of trigger to the complete stop of the wheelchair and verify if it is within 1s
2. LED must be lit when emergency state is recognised by the system	A) Manually trigger the emergency response for both the push button and system programming and check if the LED is lit within 0.1s

2.3.6 Motor Subsystem

The motor subsystem will consist of a 4.5V Dagu HiTech Electronic Motor and an H-bridge to control the polarity of the motor output. The speed of the wheelchair will be determined as a function output of flex sensor data. The motor provides a rotation per minute specification that guarantees a comfortable motion experience.

Requirement	Verification
1. Given an input voltage of 4.5V and an operating current of 190 mA, the speed should be between 80-100 rotations per minute.	A) We will use an oscilloscope to discern the rotations per minute of the motor given the waveform specifications that are expected. B) Once we input the appropriate voltage and current, the output waveform will be used to determine the frequency of the motor. C) Using the known formula 1rpm = 1/60 Hertz, we can test if the rpm lies in the range that we expect it to be.

2.4 Tolerance Analysis

A critical factor which enables the safety of the user is how we interpret the data. The output of our sensor subsystem is a function of the data from the flex sensors and the IMU. This data is the foundation of the project and we have to be certain about the variability we can expect in it. To make sure that the values we see will be appropriate, we have designed verification analysis procedures that rigorously test the whole pipeline of data flow. The band pass filter follows the function that allows us to keep the values in range is defined as:

$$
\begin{aligned}
f(x) \;=\; & x && : \; 0 \le x \le 7 \\
& 7 && : \; x > 7 \\
& 0 && : \; x < 0
\end{aligned}
$$

This formula guarantees that any fluctuation in the input will not carry over to the output ensuring that the user will not experience any discomfort during usage. The system automatically cuts off the speed at 7mph, ensuring that the speed range (0mph-7mph) is maintained at all times.

The emergency button provides a second barrier of safety for the person driving the wheelchair. When the button is pressed, it will disable the power supplied from the motor drivers to the wheel and the vehicle will be brought to a stop.

It is imperative that the wheelchair comes to a stop within 1s and that the distance covered during the deceleration is no more than 1.25m - 1.75 m.

$$
\begin{gathered}
d_{max} = \text{1.25m - 1.75m} \\
u = v_{current} \\
v = 0 \; m/s
\end{gathered}
$$

Here, we have defined d_{max} to be the maximum allowed distance. Since the maximum allowed velocity is 7mph,

$$u_{max} = 7mph = 3.12928 \; m/s$$

Then, to find the deceleration range, we use the formula:

$$v^2 = u^2 + 2\alpha S$$

$$\text{where, } \alpha : acceleration$$
$$S : distance$$

Substituting, we get:

$$0 = v_{current}^{2} + 2\alpha_{max} \times 1.25 \quad \text{and}$$
$$0 = v_{current}^{2} + 2\alpha_{min} \times 1.75$$

Therefore,

$$\alpha_{max} = -\frac{v_{current}^{2}}{2.5}$$
$$\alpha_{min} = -\frac{v_{current}^{2}}{3}$$

Substituting for the maximum possible velocity for $v_{current}$,

$$\alpha_{max} = \frac{-(3.12928)^2}{2.5} = -3.916957\ m/s^2$$
$$\alpha_{min} = \frac{-(3.12928)^2}{3} = -2.797826\ m/s^2$$

From this calculation, we find the optimum range of deceleration to be between $2.797826\ m/s^2$ and $3.916957\ m/s^2$.

This is a picture of the wheel we will be using for the toy car. The radius of this wheel is measured to be 0.0325m and its rotational speed is 80rpm, as discovered from the datasheet.

$$r_{wheel} = 0.0325m$$

Figure 10: Wheel Toy Car [10]

The mass of the motorized toy car is estimated to be 0.37kg.

$$m = 0.37\ kg$$

We now have the mass of the car and we have also calculated the optimum deceleration needed. With these parameters, we can now calculate the force and torque on the wheel using the following formulae:

$$\begin{gathered} Force\ (F) = m \cdot \alpha \\ Torque\ (\tau) = F \cdot r \end{gathered}$$

Substituting the values, we get a range for the force values as follows:

$$\begin{gathered} F_{min} = 0.37 \times 2.797826 = 1.0349\ N \\ F_{max} = 0.37 \times 3.916957 = 1.4493\ N \end{gathered}$$

$$\begin{gathered} \tau_{min} = 1.0349 \times 0.0325 = 0.03363\ Nm \\ \tau_{max} = 1.4493 \times 0.0325 = 0.0471\ Nm \end{gathered}$$

In the case of DC motors, the output torque is directly proportional to the current I by a torque constant k_T specific to the motor.

$$\tau = I \cdot k_T$$

The torque constant for our motor is $0.32\ Nm/A$.
Now, to find the current I, we have $I = \frac{\tau}{k_T}$

$$I_{max} = \frac{0.0471}{0.32} = 0.147\ A$$

$$I_{min} = \frac{0.03363}{0.32} = 0.105\ A$$

By this analysis, we conclude that the current will be in the range of 0.105 to 0.147 Amperes which is within the tolerance level of the motor subsystem (can take a maximum of 0.25 A).

3. Cost and Schedule

3.1 Cost Analysis

3.3.1 Labor Costs

Name	Rate Per Hour	Hours	Sum	Total (including 2.5)
Tanvi Shah	$45	150	$6,750	$16,875
Lakshya Lahoty	$45	150	$6,750	$16,875
Anumay Mishra	$45	150	$6,750	$16,875
Total				**$50,625**

Table 1: Labor Costs

3.3.2 Part Costs

Part Name	Quantity	Manufacturing Company	Item Code / Details	Cost
Microcontroller Chip Atmega328p	1	Sparkfun	AVR 28 Pin 20MHz 32K 6A/D	$4.30
Inertial Measurement Unit	1	Sparkfun	LSM9DS1	$15.95
Flex Sensor	5	Sparkfun	Sen-10264	$39.75 ($7.95 each)
Weather Resistant Pair of Gloves	1	Amazon	Impact	$14.99
Lithium Ion Battery	2	Adafruit	3.7V 2000mAh (PID - 2011)	$25.00 ($12.50 each)

Voltage Regulator	1	Sparkfun	5V 250mA L4931 - 50 to 92	$1.50
Push Button Switch	1	Adafruit	PID - 3870	$1.00
LED	1	Adafruit	N/A	$0.50
Toy Car (Testing Purposes)	1	Amazon	N/A	$5.00
Total				**$107.99**

Table 2: Part Costs

3.3.3 Combined Total Costs

Cost Item	Total
Labor	$50,625
Parts	$107.99
Combined Total	**$50,732.99**

Table 3: Total Costs

3.2 Schedule

Week Of	Job	Task Responsibility
March 3, 2020	Design Review	Everyone
	Initial Conversation with Machine Shop (if needed based on review feedback)	Everyone
	Submit Order for Needed Parts	Anumay

	Begin Software Module Development	Tanvi
	Finalize Architecture and Device Design	Lakshya
	Complete PCBway Audit	Anumay
March 9, 2020	Complete Team Evaluation I	Everyone
	Complete Soldering Assignment	Everyone
	Complete Early Bird PCBway Order	Everyone
	Software Module Development - Initial Microcontroller Programming	Tanvi
	Further Development of Glove Based Wheelchair Navigation - Work on Other Module Design	Anumay, Lakshya
March 16, 2020	Spring Break	
March 23, 2020	Integrate Flex Sensors and IMU into Gloves	Everyone
	Work on Emergency Response Module and Power Module	Anumay
	Work on Microcontroller Programming - integrated based on Sensors' Data	Tanvi
	Work on Power Module and Sensor Module	Lakshya
March 30, 2020	Complete Individual Progress Reports	Everyone
	Complete Power Module and Sensor Module	Lakshya
	Complete Software Module - Microcontroller Programming	Tanvi
	Complete Emergency Response Module and Power Module	Anumay
April 6, 2020	Complete Final Round PCBway Order	Everyone
	Test Software Module	Tanvi

	Test Emergency Response and Power Module	Anumay
	Test Power and Sensor Module	Lakshya
April 13, 2020	Assemble Modules and Build Device	Everyone
	Prepare for Mock Demo	Everyone
	Refine Prototype	Everyone
	Amendments to Software Module	Tanvi
	Amendments to Emergency Response and Power Module	Anumay
	Amendments to Power and Sensor Module	Lakshya
	Prepare for Mock Demo	Everyone
April 20, 2020	Mock Demo	Everyone
	Work on Final Paper	Lakshya, Anumay
	Work on Final Presentation	Tanvi, Lakshya
	Work on Demonstration	Anumay, Tanvi
April 27, 2020	Demonstration	Everyone
	Complete Final Presentation	Tanvi, Lakshya
	Complete Final Paper	Anumay
May 5, 2020	Final Presentation, Lab Notebook Submission, Final Paper, Teamwork Evaluation II, Award Ceremony and Pizza	Everyone

Table 4: Schedule

4. Ethics and Safety

There are various concerns and things we need to keep in mind when we build this device from a safety standpoint, few of which have been elaborated:

- Individuals using this will mostly be differently abled and hence there are risks that those individuals face if they don't understand the sensitivity of the control they have. To tackle this, we suggest having a caretaker around when the individual learns how to use the device to prevent accidents. Gradually, the individual will get accustomed to the sensitivity and will be more confident operating it.

- Wheelchairs have the ability to go at speeds that may cause discomfort to these individuals. Also, accidents are more frequent at high speeds and we need to address this issue. We researched the average speed of a motorized wheelchair and have a system in place to cut-off power to the motor if the speeds start going beyond that limit.

- Temperature has an impact on the sensitivity of the sensors we are using and faulty data can put the individual at high risk. To make sure this doesn't become a limiting factor in the functioning of the device, we will be using filters to keep the data in appropriate working range. Any change in sensitivity of sensors should be reported immediately to get it replaced.

- We will comply with the design requirements, test procedures and performance requirements as mentioned in the WC19 Safety Standard for Wheelchairs.

Processing Subsystem poses the greatest risk factor in our project. It is critical that we evaluate all the data correctly otherwise it will lead to an uncomfortable experience and the user can tend towards dangerous outcomes. The data from the IMU must be read correctly to sense the appropriate direction for the wheelchair to move in. Data from the flex sensor must be correctly mapped in the appropriate range to guarantee a comfortable experience. In the end, the motive of this project is to make sure that the person using this can comfortably navigate their way on a wheelchair and getting this subsystem to function correctly is critical to the overall experience.

Our project also tackles some ethical issues that differently abled people have to face when going about their routine :

- The standard wheelchair design requiring manual effort for navigation is not comfortable for all individuals. These challenges rarely get attention and our project is attending to the needs of those people in accordance with the rule stated in IEEE that tell us about our responsibility to improve understanding of people about the societal impacts of modern technology [4].

- Since a very small subset of people face the challenge we are tackling, not enough people are working towards improving their lives. This project is an attempt to popularize the various disabilities in humans that make completing everyday tasks a challenge.

- There are also concerns about someone maliciously trying to rupture the system. To counter this, we will try to create all the components such that it is not very accessible from the exteriors, giving only the user the control of the wheelchair.

We acknowledge the challenges we face ahead of us to make this project as safe for the user as is possible while also complying with the code of ethics specified by IEEE. We have procedures in place to help us achieve both such that we can guarantee the best experience for the individual.

5. Citations

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