ECE 445

Senior Design Laboratory

Pitched Project Proposal

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Dynamic Seat Cushion

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1. Introduction

1.1 Problem

Pressure sores are ulcers that break down the skin and underlying tissue in body areas that experience prolonged pressure. Approximately 3 million people worldwide develop pressure sores every year, with over 500,000 cases requiring extended hospitalization [1]. Wheelchair users face a higher risk of developing pressure sores and their best solution today is to manually adjust every 15-30 minutes. However, those with limited mobility and/or sensation may struggle with manual readjustments and/or with feeling when a readjustment is needed. As such, this group of wheelchair users faces an even higher risk when it comes to pressure sores.

While conventional cushions provide some relief, the solution they offer is static, limited, and does not eliminate the risk of pressure sores due to its inability to adapt to the user. Moreover, research into dynamic solutions is limited and no commercially available dynamic solution exists.

1.2 Solution

Our solution uses a combination of resistive sensors, a programmable pneumatic pump, and a thermoplastic polyurethane bladder to create a dynamic seat cushion that will relieve pressure for wheelchair users. The sensors will be used to detect areas and time durations of high pressure(s) so that a microcontroller can translate these signals into inflation controls for cushion bladders around pressure points.

Throughout this project, we will be collaborating with Dr. Golecki's research group. We will be implementing the electronics portion, which includes the sensor array, a user interface, the power subsystem, and a microcontroller. With these subsystems, we will develop a high-resolution sensor array that detects high-pressure areas on the seat over time and relieves pressure through selective inflation/deflation of cushions in the bladder. We will be optimizing the design for efficiency and compactness.

1.3 Visual Aid

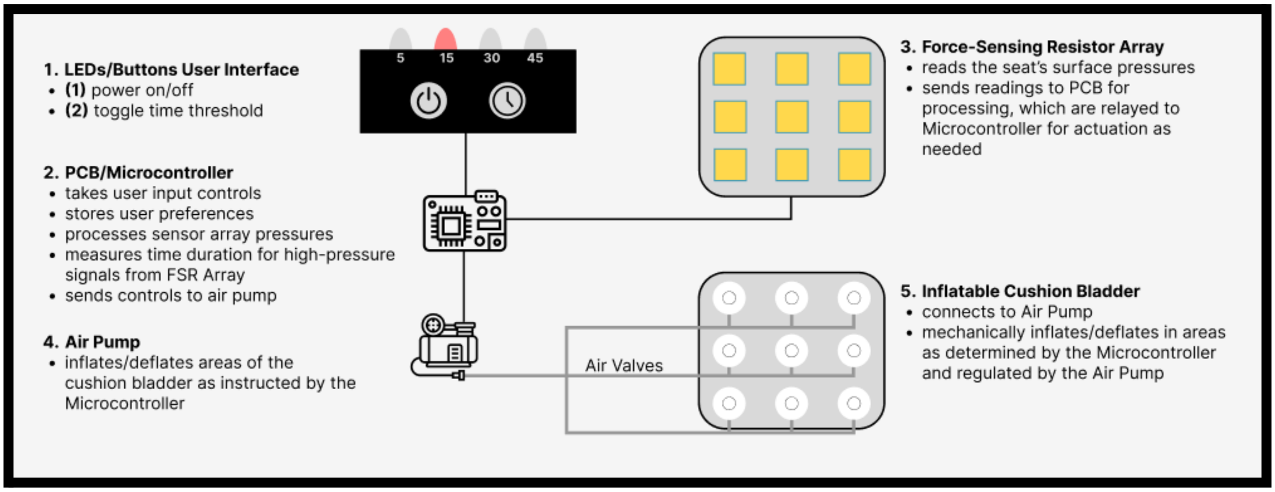

Figure 1: Dynamic Seat Cushion Functionality Overview

1.4 High-Level Requirements

The primary success criteria for our project are as follows:

- The dynamic seat cushion fits within the dimensions 12in. Wide x 14in. Deep x 4in. High, which is suitable for standard manual and electric wheelchairs [2].
- The sensor array signals the microcontroller when a target area exceeds the pressure threshold. While this signal is high, the microcontroller counts down to determine if the target meets the time threshold which will be user-designated.
- When both thresholds are met, the microcontroller inflates areas surrounding a target such that the target drops below the pressure threshold.

2. Design

2.1 Block Diagram

The block diagram consists of our 4 main subsystems: power, user interface, sensor array, and programmable air.

The power subsystem will handle battery charging/protection, and voltage regulations. The user interface subsystem consists of four LED lights and two buttons for user interaction. The sensor array subsystem is an array of force-resistive sensors that will signal areas of high pressure to the microcontroller. The programmable air subsystem takes instructions from the microcontroller to inflate the bladders around areas of high pressure. The microcontroller is part of all subsystems.

Green and orange arrows represent power and data lines, respectively. Button 1 is a switch for power. When closed, the battery will connect to the voltage regulator to power on the device. Button 2 is a soft button that toggles device settings, to be programmed with the microcontroller.

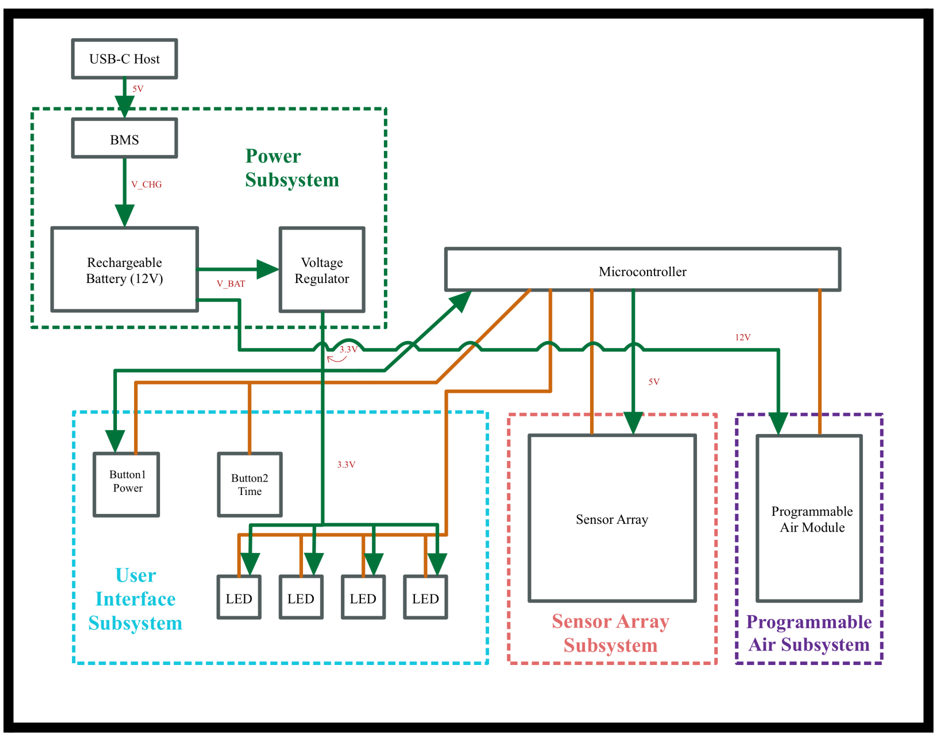

Figure 2: Schematic Block Diagram of Subsystems

2.2 Physical Design

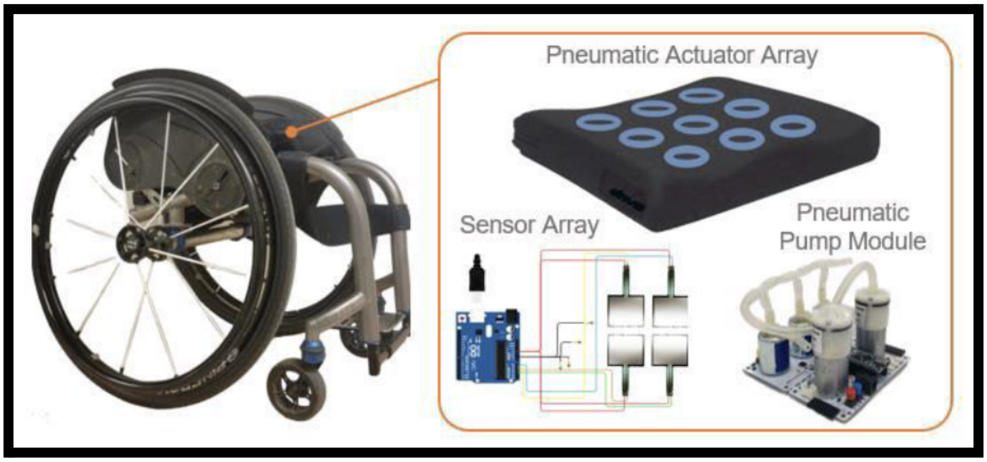

Figure 3: Physical design provided by Dr. Golecki's group [1]

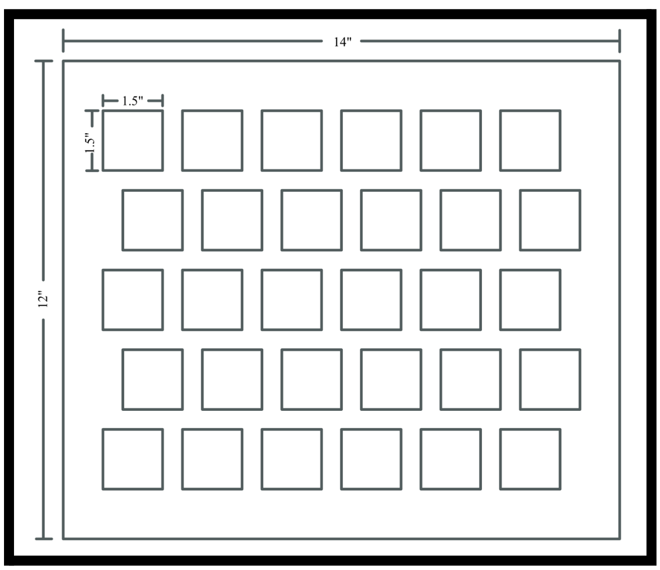

Figure 4: Array of Sensors on Plastic Sheet

The array will consist of 30 individual sensors, arranged in a 6x5 formation. Each sensor is 1.5”x1.5” and the seat cushion dimensions are 12”x14”. The sensors will be placed on a flat perforated plastic sheet so that each of their solder tab tails can be fed beneath this surface.

2.3 Subsystem Overview

2.3.1 Power Subsystem

The power subsystem will be in charge of powering all other subsystems. It will house four-3V rechargeable lithium-ion battery cells in series to supply 12V. These cells will be paired with a BMS (battery management system) consisting of two 2-cell balancers and one 4-cell protector. The battery pack will feed into 3.3V and 5V voltage regulators which will supply power to the microcontroller (STM32F103C8) and sensor array subsystem, respectively. It will also be connected to the UI subsystem for power.

2.3.2 User Interface Subsystem

The user interface subsystem houses four LEDs and two buttons. Only one LED will be on at a time to display the current time setting; this setting is stored by the microcontroller between power cycles. Button 1 (switch) allows the user to switch the device power on or off. Button 2 (soft) bounces instruct the microcontroller to toggle to the next time setting, turn off the previous LED, and turn on the next LED.

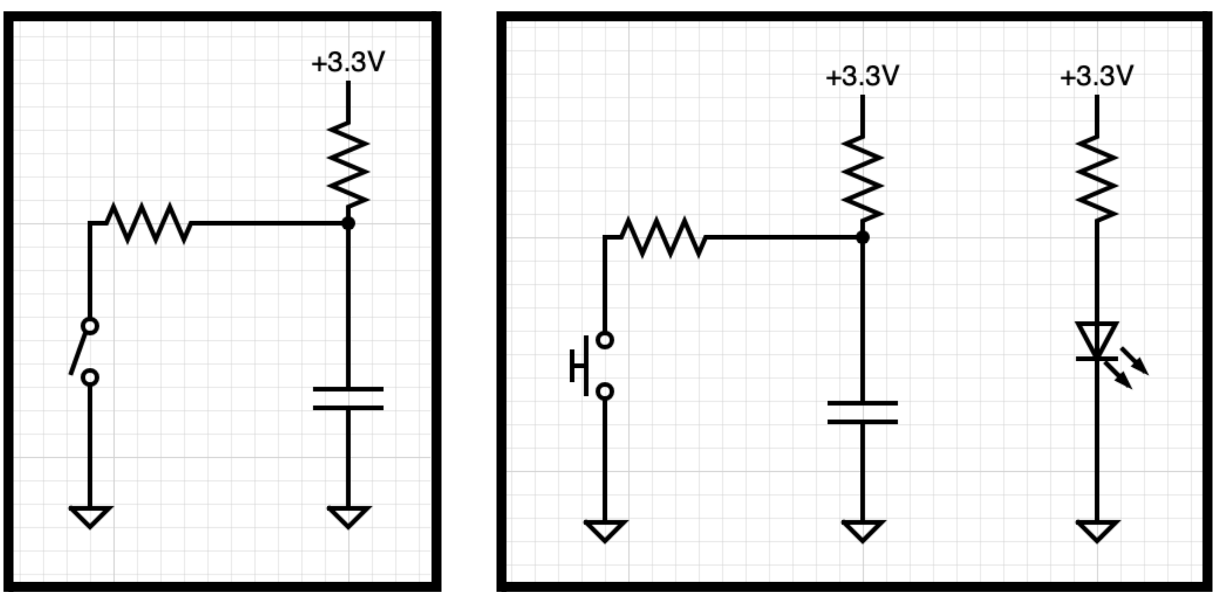

Figure 5: Button 1 Switch Schematic (Left) and Button 2 (Soft) with LED Schematic (Right)

2.3 Subsystem Overview (*cont.*)

2.3.3 Sensor Array Subsystem

The sensor array subsystem will consist of 30 square Force-Sensing-Resistors to provide a high-resolution pressure distribution of the user's weight over the wheelchair cushion. The microcontroller will receive this data to handle its control functions to the programmable air subsystem.. The sensor array subsystem will receive power from microcontroller/PCB.

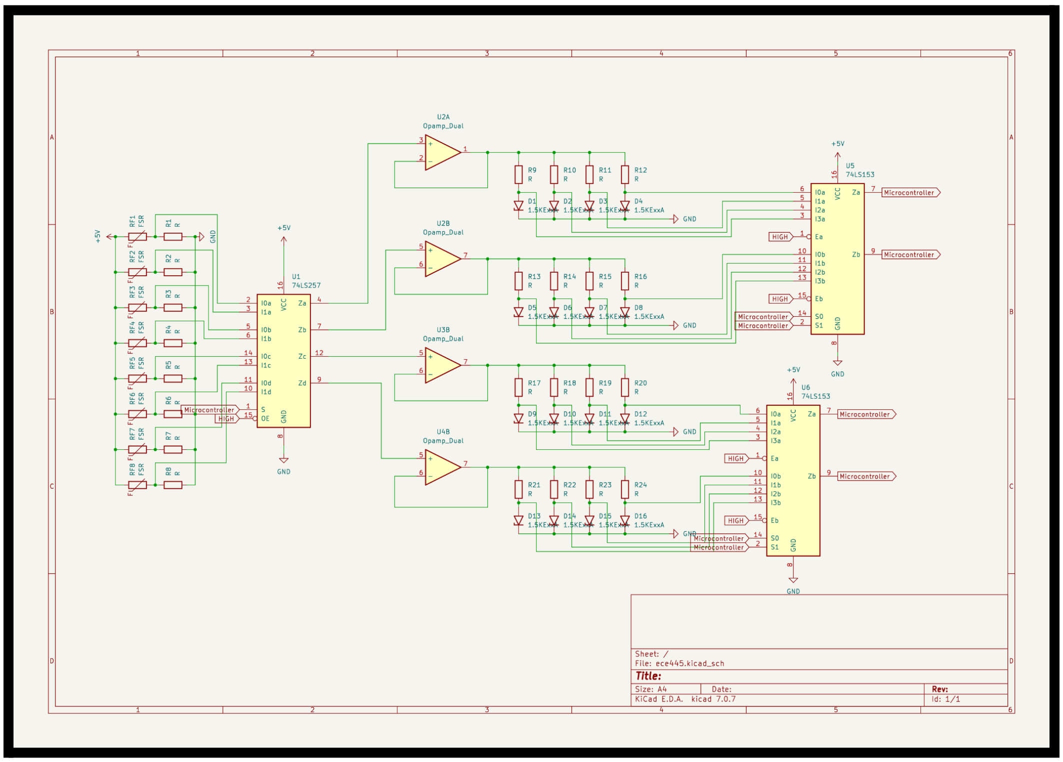

Figure 6: Sensor Array Schematic (sample for 8 FSRs)

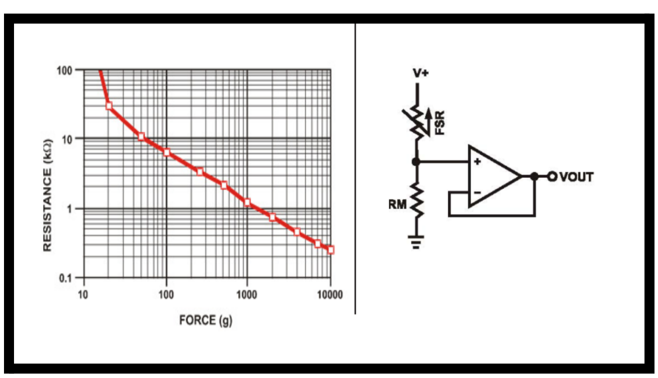

Figure 7: Sensor schematic with force sensing resistor and Force (g) vs. Resistance (kΩ) [7]

2.3 Subsystem Overview (*cont.*)

2.3.4 Programmable Air Subsystem

The programmable air subsystem will operate the air pump using instructions from the microcontroller to inflate and deflate the bladders. It will inflate and/or deflate the bladders depending on the signals received from the microcontroller. It will also provide pressure data to the microcontroller to prevent overinflation of cushion bladders.

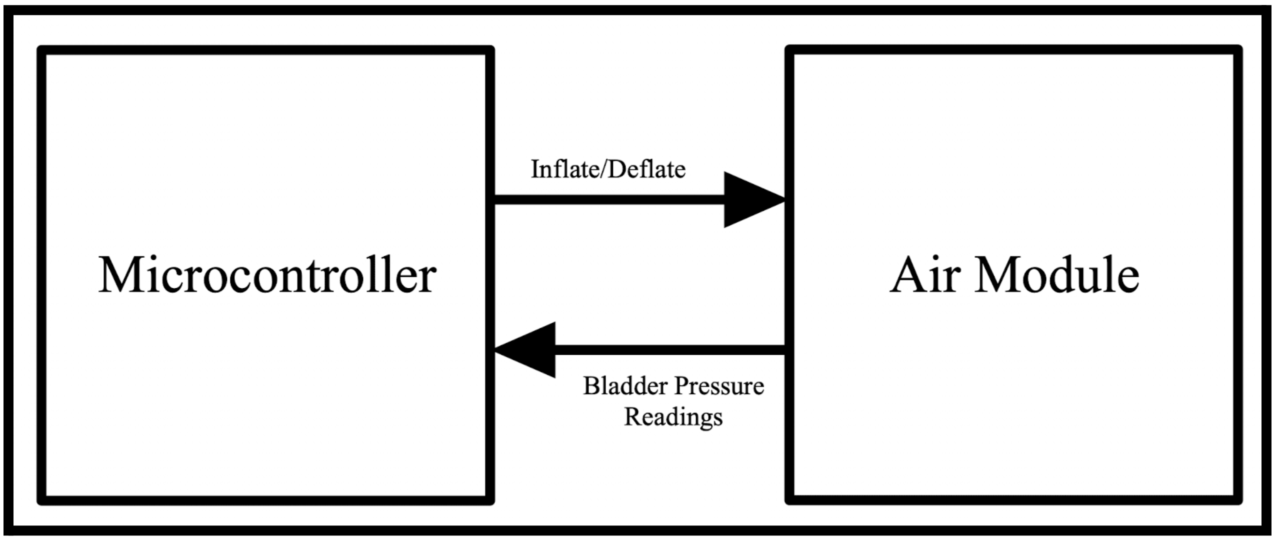

Figure 8: Basic connections (1 of 6) between microcontroller and programmable air module

2.4 Subsystem Requirements

2.4.1 Power Subsystem

Requirements	Verification
● The system must provide a stable supply of 3.3V (±0.1V) to the microcontroller and the User Interface Subsystem.	1. Connect the output of the voltage regulator to a load on a separate test breadboard which is also connected to the ground. a. These are the loads that will be used for verification i. 1kΩ Resistor ii. 2.5kΩ Resistor iii. 10kΩ Resistor 2. Probe the output of the voltage regulator and ground using an oscilloscope. 3. Record voltage drop readings across the load.
● The system must provide short circuit protection from the output of the voltage regulator. Power will shut off with more than 150mA being drawn from the voltage regulator.	1. Connect output of voltage regulator to a 10 Ω resistor on a separate test breadboard. 2. Probe the oscilloscope in series to the resistor and ground. 3. Turn the power system on and record current readings from the oscilloscope.
● The BMS will not draw more than 1.5A from USB-C input.	1. Plug in a 5W charger into a 110V outlet. 2. Connect the power system via a USB C test power meter. 3. Record amperage through power meter.

2.4 Subsystem Requirements (cont.)

2.4.2 User Interface Subsystem

Requirements	Verification
• On/Off functionality through the user controlled button.	1. Using an oscilloscope, probe the output of the voltage regulator and ground. 2. Turn the switch on 3. Record whether or not probe reading 3.3 (±0.1V). 4. Turn the switch off 5. Record whether or not probe reading is under 0.1V.
• User is able to cycle through the default time thresholds with Button 2 and the time is correct.	1. Turn the power on. 2. Click Button 2 and visually see if the time setting increases (LED light for next time is on from 5, 15, 30, 45 one after the other and then back to 5). 3. Double check each time setting is accurate to the time by using a timer. a. Place heavy object on sensor. b. Wait the duration of time with a timer. c. Check if the output of the microcontroller (inflate/deflate signal) is HIGH.
• User's previous time preference is stored.	1. Turn the power on. 2. Choose a time to set to using Button 2 (ex. Set time to 15 minutes). 3. Turn the power off. 4. Turn the power on. 5. See if the time preference is stored by checking if the LED next to the set time is on and timing it. 6. Repeat for different time settings

2.4 Subsystem Requirements (cont.)

2.4.3 Sensor Array Subsystem

Requirements	Verification
• Force Sensing Resistors (FSRs) in the array are able to individually transmit data to the microcontroller and not interfere with other FSRs in the array.	1. Using a voltmeter or oscilloscope, probe the Vout of the FSR voltage divider and ground. 2. Place a 1kg weight on FSR, nothing on other FSRs. 3. Verify 2V (±0.1V) on probe reading. 4. Probe unweighted FSR the same way and verify less than 0.5V. Repeat for every unweighted FSR in the array 5. Repeat for every individual FSR in the array.
• FSR array avoids saturation up to 2kg per FSR in normal use.	1. Using a voltmeter or oscilloscope, probe the Vout of the FSR voltage divider and ground. 2. Place a 2kg weight on FSR, nothing on other FSRs. 3. Record probe reading. 4. Place a 100g weight on top of the 2kg weight. 5. Record probe reading and verify a difference of at least 50mV 6. Repeat for every single FSR in the array.
• Microcontroller instructions for bladder inflation operate within 100ms of each other.	1. Using the oscilloscope, probe the individual bits of bladder inflation opcode (4-bit) from the microcontroller and ground. 2. Reset the opcodes to 0000 3. Place weight on FSR array to initiate opcode change to 0101. 4. Record and verify the time from the initial bitchange until the last bit change is under 100ms. 5. Reset the opcode to 0000. 6. Record and verify the time from the initial bitchange until the last bit change is under 100ms.

2.4 Subsystem Requirements (cont.)

2.4.4 Programmable Air Subsystem

Requirements	Verification
• Air pump draws less than 10mA of current when not in operation	1. Add weights to initiate airmodule pumps. 2. Reset opcode to 0000 by removing all weights. 3. Use a multimeter to measure the amperage and verify current is less than 10mA. 4. Record results in lab notebook.
• Air pump stops within 100ms of when desired pressure is achieved in the bladder.	1. Using the oscilloscope, probe the Vout of the Vout of pressure sensor. 2. Also probe the opcode output and ground. 3. Record and verify the time delay between pressure sensor Vout reaching **SOME VALUE (waiting for Goleki group)** and the opcode output falling below 0.2V (±0.1V).
• Air pump activates within 100ms of the opcode high signal.	1. Reset opcode to 0000 by removing all weights. 2. Using the oscilloscope, probe the opcode output for voltage and pump power line for current. 3. Record and verify the time delay between opcode high and increase in pump current draw.

2.5 Tolerance Analysis

Our design utilizes multiple Square Force-Sensing Resistors (FSRs) over the wheelchair seat cushion to obtain a high-resolution image of the seat's surface pressure. The model we will use is the FSR UX 406 by Interlink Electronics. Its sensing range is 0.10 N to 100 N over an active area of 1.5 in^2 [3].

Assuming an average user mass of 70 kg, the maximum gravitational force exerted on their seat is 686 N or ~155 lbs. While the seat surface is 12 in W x 14 in D, most of the user's weight will be concentrated in a 12 in x 6 in area centered along the width and positioned to start at the very back of the seat [2]. As such, we are focused on obtaining a high-resolution pressure reading within a 72 in^2 area.

For an average user, an equally distributed surface pressure in this 72 in^2 area would be 155 lbs/72 in^2 or ~2.15 PSI. High-resolution readings from highly sophisticated and expensive systems, such as the TACTILUS, often tolerate up to 200 mmHg (3.87 PSI) [4], although the average user would rarely exceed 130 mmHg (~2.50 PSI) anywhere on the seat [1]. Thus, we should be concerned with measuring up to 2.15 PSI for an FSR grid area.

Recall that our selected FSR model can measure up to 100 N over an active area of 1.5 in^2 which translates to 66.67 N / in^2 and equivalently ~15 PSI. As such, we can confidently incorporate multiple FSR UX 406s into our design to create a high-resolution discrete pressure mapper by using an FSR array.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Parts/Materials

Description	**Manufacturer**	**Quantity**	**Unit Price**	**Total Cost**
Force-Sensing Resistor: 1.5″ Square (FSR UX 406)	Interlink Electronics	30	$4.99	$149.70
3kΩ Resistors	YAGEO	30	$0.00840	$0.42
Op-Amps	Microchip Technology	20	$0.63	$15.75
IC 74LS257 Quad 2-Line to 1-Line Data Selector/Multiplexer	Major Brands	4	$0.99	$3.96
Dual 4-1 Multiplexer SN74LS153DR	Texas Instruments	20	$0.775	$15.50
5V Converter AP63205WU-7	Diodes Incorporated	1	$0.87	$0.87
3.3V Converter AP63203WU-7	Diodes Incorporated	1	$0.87	$0.87
Lithium Ion 4-Cell Battery Charging IC	Renesas Electronics America Inc	1	$8.89	$8.89
Lithium Ion 4-Cell Battery Protector	Texas Instruments	1	$1.10	$1.10
Lithium Ion 2-Cell Battery Balancer	Texas Instruments	2	$5.48	$10.96
Lithium Ion 3V 45mAh Cell	Panasonic-BSG	4	$2.75	$11.00
USB-C Input Port	Amphenol ICC	1	$0.48	$0.48
TOTALS	-	**115**	-	$219.50

Table 1: Cost Analysis

3.1 Cost Analysis (*cont.*)

3.1.2 Labor Costs

The average starting salaries for an electrical engineer UIUC graduate is $87,769 in 21-22 and for a computer engineer UIUC graduate, it is $109,176 [6]. Since there are electrical and computer engineers in our group, we will take the average of that, which comes out to roughly $98,473, which equates to roughly $49.24 per hour.

Category	Estimated Hours (Angelica, Anthony, Eric)
Circuit Design	(17, 6, 17) = 40
Board Layout and Design Check	(10, 10, 10) = 30
Soldering and Assembly	(6, 7, 7) = 20
Software Component	(5, 10, 5) = 20
Signal Interpretation	(5, 0, 5) = 10
Debugging	(30, 30, 30) = 150
Documentation and Logistics	(34, 33, 33) = 100
Total Hours	**370**

Table 2: Estimated Hours

The project's total labor costs comes out to a total of

$$2.5\ (overhead\ multiplier)\ \times\ \$49.24/hour\ \times\ 370\ hours\ =\ \$45,547.00$$

3.1.3 Total Costs

The total cost of this project is

$$(Parts\ +\ Labor)\ =\ \$45,766.525$$

3.2 Schedule

- Week of 09/25; Week 6
  - Design Document
  - Schematic review and feedback
  - Work on PCB
- Week of 10/02; Week 7
  - PCB review and feedback
  - Design review
  - Order parts
- Week of 10/09; Week 8
  - Order PCB parts
  - Order PCB
  - Sensor and microcontroller logic development
- Week of 10/16; Week 9
  - Assemble PCB
  - Component testing
  - Debug
- Week of 10/23; Week 10
  - Order second PCB
  - Debug
- Week of 10/30; Week 11
  - Debug and
- Week of 11/06; Week 12
  - Debug and review
  - Prepare for demo
- Week of 11/13; Week 13
  - Mock Demo
  - Prototype debug and review
  - Work on final Demo and presentation
- Week of 11/20; Week 14
  - Fall Break
- Week of 11/27; Week 15
  - Final Demo
  - Debug + Review
  - Work on final presentation and paper
- Week of 12/04; Week 16
  - Final Presentation
  - Final Paper

4. Ethics and Safety

4.1 Relevant IEEE Code of Ethics

Our group will abide by the IEEE Code of Ethics adopted by the IEEE Board of Directors. Our device can be dangerous if not designed carefully. We will hold ourselves to the highest ehtical standards in which some are listed below.

1. **To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others [5]**

   We will be collaborating with Dr. Golecki's research group. They have extensive knowledge of the project's subject matter compared to our group members. Thus, we will regularly ask for their feedback on our work. Strong communication with Sponsor is crucial to their own objectives, as well as our ability to fulfill their expectations. Most importantly, we will properly credit their contributions as they relate to our work.

2. **To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations [5]**

   The Golecki Group is the originator of the project/product and they are collaborating with us due to our specialization in electronics engineering. As such, our work also serves to improve our own technical competence in this field. Moreover, we will not act as primary contributors to mechanical design decisions since we are not qualified by training or experience to do so. By dividing tasks based on our respective strengths in this way, we are more likely to succeed in the development of this project.

3. **To treat all persons fairly and with respect, and to not engage in discrimination based on characteristics such as race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression [5]**

   Our project aims to serve users who rely on wheelchairs for daily life. This necessitates collaboration and testing with target users. Treating all persons fairly, with respect, and without discrimination is a golden rule, and it is especially relevant in the context of this project since our members do not hold the relevant personal experiences that our target users do. As such, we must strongly value and consider their feedback in order for our project to make progress in extending the target users' access to a comfortable lifestyle and preventative healthcare measures.

4.1 Relevant IEEE Code of Ethics (*cont.*)

4. **To treat all persons fairly and with respect, and to not engage in discrimination based on characteristics such as race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression [5]**
   Our project aims to serve users with disabilities who are wheelchair-bound, which necessitates collaboration, feedback, and testing with target users as well as knowledge transfers with relevant stakeholders. While treating all persons fairly, with respect, and without discrimination is a golden rule, it is especially relevant in the context of this project since members of our group do not hold the relevant personal experiences that our target users do. As such, it is important that we strongly value and consider their feedback in order for our project to succeed and to make progress toward extending the target users' access to a comfortable lifestyle and preventative healthcare measures.

4.2 Safety Concerns and Precautions

With regard to safety and regulations that are relevant to this project, we consider the following:

1. **Battery Failures**
   We will examine dangers associated with batteries being close to a person's body, as well as the risks of lithium-ion batteries in general. We aim to address the risk of overheating by researching prevention methods and deliberating on appropriate precautions. From this, we will strongly consider and deliberate on the best location for the battery. In addition, we will be including a safety manual for our device, with an emphasis on mitigating dangers associated with reusable batteries. For example, procedures that promote safe use include storing the device in a cool, dry, and well-ventilated area and warnings that minimize risks include not replacing the included batteries.

2. **Air Pump Failures**
   We will be considering the accuracy of cushion inflation, especially with regard to the risk of the air pump overinflating a cushion which could lead to popping and potential injury. We will also take precautions with regard to setting appropriate limits to the level(s) of inflation that are available to the user.

3. **Circuit Failures**
   We will be extremely cautious with configuring the circuitry within the cushion itself. If a short-circuit were to occur, it could cause injury to the user so we aim to minimize this risk by researching and following best practices for our equipment, mainly with regard to PCB component placements.

5. References and Citations

[1] J. L. Robinson et al., "DESIGN OF A CUSTOM SENSING AND ACTUATING CUSHION FOR USE IN PRESSURE RELIEF IN WHEELCHAIR USERS," Apr. 2023, doi: https://doi.org/10.1115/dmd2023-6305.

[2] "Determining the Seat Width for a Wheelchair," *Karman® Wheelchairs*. https://www.karmanhealthcare.com/determining-the-seat-width-for-a-wheelchair/#:~:text=Typical%20wheelchair%20seat%20widths%3A (accessed Sep. 25, 2023).

[3] I. E. Inc, "Pressure Measurement Sensors and Rugged Touchpads," www.interlinkelectronics.com. https://www.interlinkelectronics.com/fsr-ux-400

[4] "Tactilus | Compression Force Sensing Resistor (fsr) | Force Sensing Resistors | Force Sensing Resistors | Tactilus | Surface Pressure Indicator | Mapping | Force Sensing And Profiling," *www.sensorprod.com*. https://www.sensorprod.com/tactilus.php

[5] IEEE, "IEEE Code of Ethics," *ieee.org*, 2020. https://www.ieee.org/about/corporate/governance/p7-8.html

[6] Grainger Engineering Office of Marketing and Communications, "Salary averages," Electrical & Computer Engineering | UIUC, https://ece.illinois.edu/admissions/why-ece/salary-averages (accessed Oct. 3, 2023).

[7] "FSR 406 Data Sheet," Interlink Electronics, https://cdn-shop.adafruit.com/product-files/1075/2010-10-26-DataSheet-FSR406-Layout2.pdf.