ECE 445

Senior Design Laboratory

Pitched Project Proposal

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Dynamic Seat Cushion

Team No. 34:

Angelica Fu
(ahfu2@illinois.edu)

Anthony Cruz Macedo
(acruzm3@illinois.edu)

Eric Cheng
(shcheng2@illinois.edu)

TA: Kai Chieh (Jeff) Chang

Professor: Victoria Shao

Sponsored by The Golecki Group

Dr. Holly Golecki, PhD
(golecki@illinois.edu)

Daniella Chapman-Rienstra
(dkc4@illinois.edu)

Isaiah Rigo
(irigo2@illinois.edu)

Jason Robinson
(jasonr5@illinois.edu)

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 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 able to detect areas and time durations of high pressure(s) and then translate these signals into inflation controls for cushions surrounding that point.

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

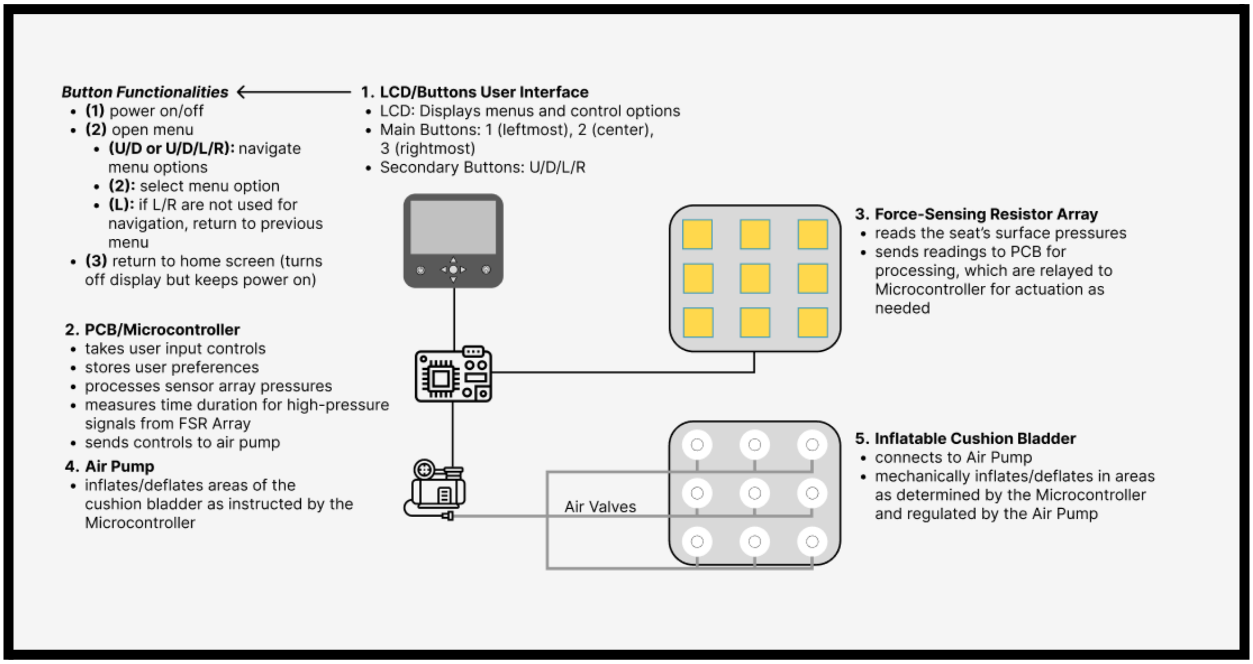

Figure 1: Dynamic Seat Cushion Functionality Overview

1.4 High-Level Requirements

The primary success criteria for our project are as follows:

- The dynamic seat cushion fits within the dimensions 22in. Wide x 15in. 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 is in charge of handling the rechargeable battery and voltage regulation. The user interface subsystem consists of the LCD display and buttons that the user will interact with. The sensor array subsystem is an array of sensors that will detect areas of pressure and send that data to the microcontroller. The programmable air subsystem takes data from the microcontroller and inflates the bladders that surround areas of high pressure. The microcontroller is part of all subsystems. Green and orange arrows represent power and data lines, respectively. Buttons 1, 2, and 3 are soft buttons that will be programmed with the microcontroller. When Button 1 is enabled, power through the voltage regulator will be allowed to go to the microcontroller, powering it on.

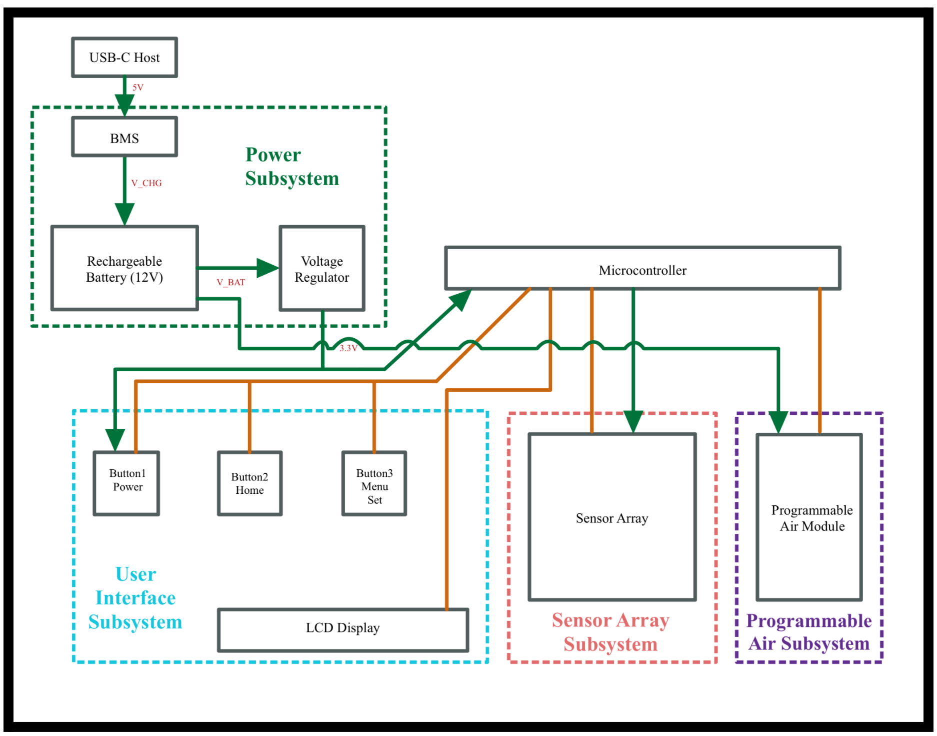

Figure 2: Schematic Block Diagram of Subsystems

2.2 Physical Design

2.3 Subsystem Overview

2.3.1 Power Subsystem

The power subsystem will be in charge of powering all other subsystems. It will house a 12V rechargeable lithium-ion battery paired with a BMS (battery management system). The battery will be connected to a 3.3V voltage regulator which will be connected to the microcontroller (STM32F103C8) and UI subsystem for power.

2.3.2 User Interface Subsystem

The user interface subsystem will house an LCD monitor along with 3 main buttons and 4 secondary buttons for user interaction. These buttons will allow the user to switch the system on and off, navigate through device settings, and change the settings. The settings implementation will be done through the microcontroller.

2.3.3 Sensor Array Subsystem

The sensor array subsystem will consist of multiple Force Sensing Resistors to examine the pressure distribution of a user's weight over the wheelchair cushion. The microcontroller will receive this information for control functions. This subsystem will be powered through the microcontroller.

2.3.4 Programmable Air Subsystem

The programmable air subsystem will accommodate the inflatable bladders and air pump to inflate and deflate the bladders. It will inflate and/or deflate the bladders depending on the signals received from the microcontroller.

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 output of 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. 1K OHM Resistor ii. 2.5K OHM Resistor iii. 10K OHM 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 OHM 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.

2.4.2 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.
● Toggle time threshold settings controlled via an internal state machine.	**1. IDK HOW the UI IS GOING TO WORK**
● Display current settings on LCD.	1. Turn the power on. 2. Verify LCD displays **current settings (starting state)** 3. Repeat and verify LCD correctly displays current settings in different settings **a. (LIST ALL SETTINGS OPTIONS)**
● Display power saving after 30 seconds of no user input.	1. Turn the power on. 2. Verify LCD screen turns on. 3. Do not interact with the system for 30 seconds 4. Verify LCD screen turns off. 5. Repeat and verify LCD turns off in different states. **a. LIST STATES (or we can probe the state output from microcontroller ig)**

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 bladder inflation opcode (4-bit) from the microcontroller and ground. 2. **SOMEHOW** set the opcodes to 0000 3. **SOMEHOW** change the opcode to 1111 4. Record and verify the time from the initial bitchange until the last bit change is under 100ms. 5. **SOMEHOW** change 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. **SOMEHOW** set the opcodes to 0000 2. Use a multimeter to measure the amperage and verify current is less than 10mA. 3. 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 between pressure sensor Vout reaching **SOME VALUE** and the opcode output falling below 0.2V (±0.1V).

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 0.50 N to 150 N over an active area of 38.10 mm^2 (~0.06 in^2) [3]. Since the FSRs are square-shaped, the active area is approximately 0.25 in x 0.25in.

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 20 in W x 18 in D, most of the user's weight will be concentrated in a 12 in x 15 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 180 in^2 area.

For an average user, an equally distributed surface pressure in this 180 in^2 area would be 155 lbs/180 in^2 or ~0.861 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 85 mmHg (1.64 PSI) anywhere on the seat [1]. Thus, we should be concerned with measuring up to 1.75 PSI for an FSR grid area.

Recall that our selected FSR model can measure up to 150 N over an active area of 0.06 in^2 which translates to 2500 N / in^2 and equivalently ~562 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	Interlink Electronics	30	10.56	316.8
Circuit components				

Table *: Cost Analysis

The project’s hardware comes out to a total of

3.1.2 Labor Costs

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 *: Estimated Hours

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.

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

$$\$49.24/hour \times \$370\ (total\ estimated\ hours) = 18,217.51$$

3.1.3 Total Costs

The total cost of this project will be

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 the danger associated with having a battery close to a person's body and how to prevent overheating within the power subsystem. We will research prevention methods and deliberate on appropriate precautions. Mainly, we will strongly consider and deliberate on the best location for the battery within the device. In addition, we will be including a safety manual for our device, with an emphasis on mitigating dangers associated with reusable batteries. For example, warnings to ensure that batteries are stored in a cool, dry, and well ventilated area and to not use batteries that are damaged or bulging.
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 limits to the level(s) of inflation 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.

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]https://ece.illinois.edu/admissions/why-ece/salary-averages