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 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 face 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

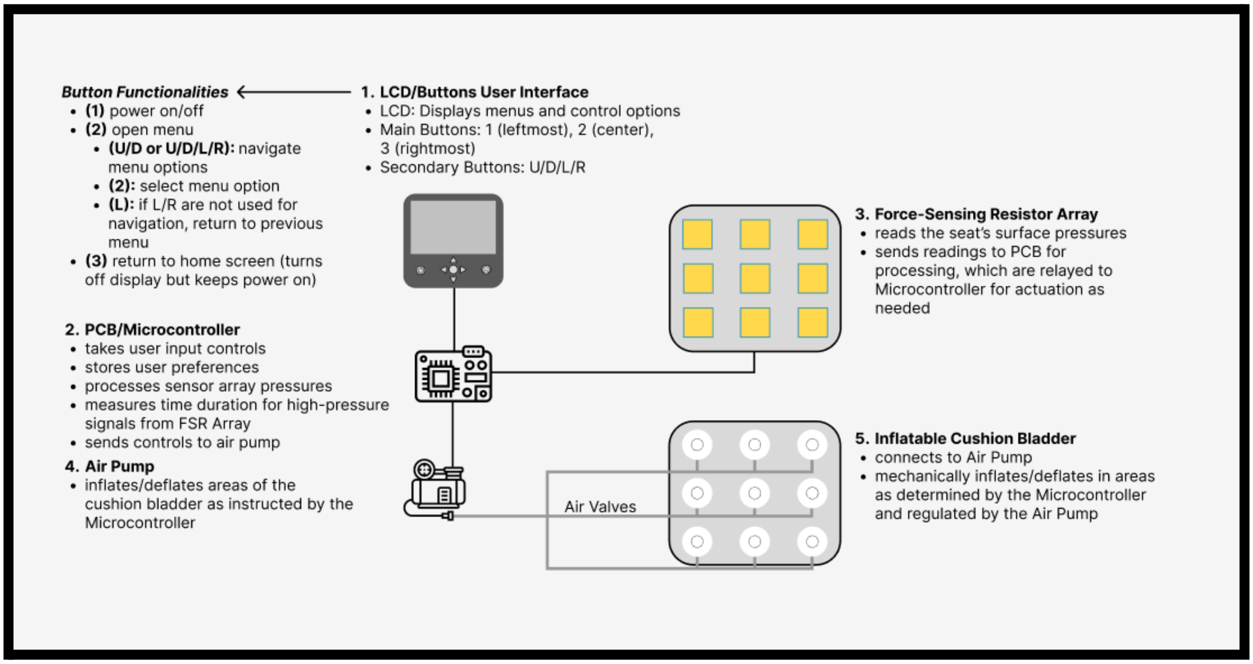

Figure 1: Dynamic Seat Cushion Functionality Overview

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

Note that the microcontroller is part of all subsystems (Power, User Interface, Sensor Array, and Programmable Air). 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.

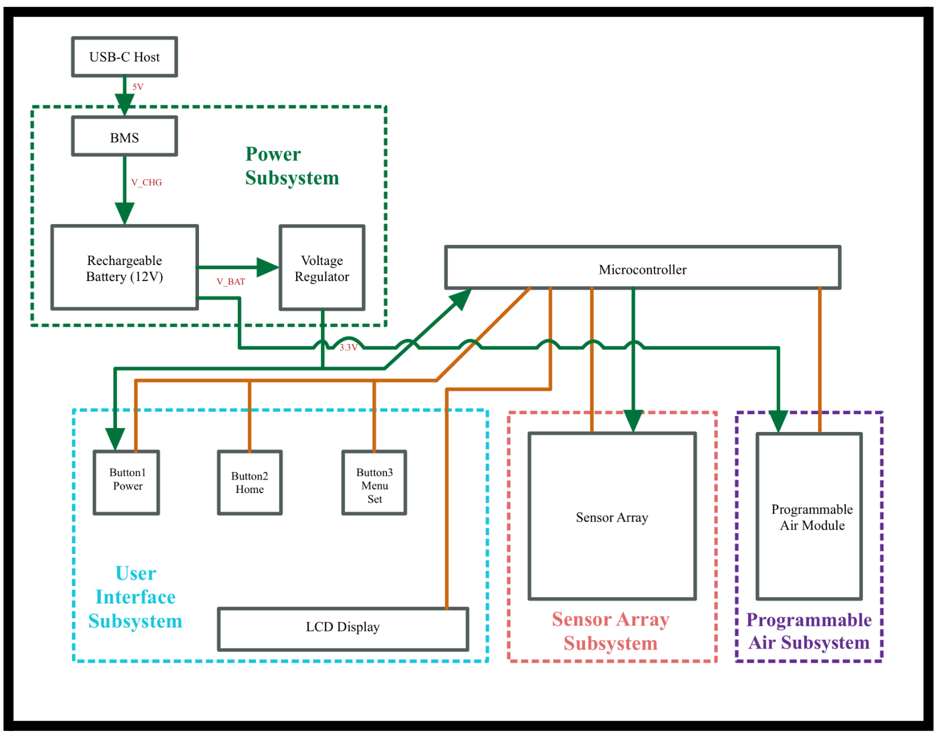

Figure 2: Schematic Block Diagram of Subsystems

2.2 Subsystem Overview

2.2.1 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.

2.2 Subsystem Overview (*cont.*)

2.2.2 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.

2.2.3 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.

2.2.4 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.

2.3 Subsystem Requirements

2.3.1 Power Subsystem

- Provide stable supply of 3.3V to microcontroller and UI Subsystem.
- Protection against irregular current and voltage spikes.
- BMS safely draws at least 1.5A from USB-C input.

2.3.2 User Interface Subsystem

- On/Off functionality through the user controlled button.
- Toggle time threshold settings controlled via an internal state machine.
- Display current settings on LCD.
- Display power saving after 30 seconds of no user input.

2.3.3 Sensor Array Subsystem

- Force Sensing Resistors (FSRs) array able to individually transmit data to microcontroller
- Sensors avoid saturation up to 30kg in normal use.
- Microcontroller able to simultaneously signal individual bladder inflation.

2.3 Subsystem Requirements (*cont.*)

2.3.4 Programmable Air Subsystem

- Air pump draws minimal to no power when not in operation.
- Programmable inflation limit based on different bladder pressure ratings.

2.4 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. Ethics and Safety

3.1 Relevant IEEE Code of Ethics

Citations of relevant IEEE Codes of Ethics that we aim to abide by, along with how they fit into the context of this project, 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.

3.1 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.

3.2 Safety Concerns and Precations

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.
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.

4. 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