University of Arkansas – CSCE Department
Capstone I – Final Proposal – Fall 2021

Care-Mate: Wheelchair Pressure Distribution Mapping System

Benjamin Allen, Clay Griscom, Hugo Serrano,
Kira Threlfall, David Whelan

Abstract

This project is designed to reduce the risk of pressure ulcers in patients bound to wheelchairs. To accomplish this a pressure array will be constructed in order to measure and warn the caregiver then the patient is in danger of developing pressure ulcers. Pressure ulcers both reduce the patient's quality of life and increase the risk of infection which can lead to major complications.

There are several devices that can measure a pressure distribution on a wheelchair, but they are expensive and may be inaccessible for the caregiver. This project will create an application that can interface with a pressure distribution sensor and package this data in an easy-to-read format.

1.0 Problem

The problem we are trying to address significantly impacts people with disabilities that are bound to wheelchairs. Their placement in a wheelchair is vitally important and if not monitored carefully those who spend significant time in a wheelchair can develop pressure ulcers. The cause of pressure ulcers ultimately comes down to blood flow. Not all patients in wheelchairs can feel when there is low blood flow. When this condition continues then it leads to the formation of pressure ulcers. Additionally, it is impossible for caregivers to really know where pressure ulcers might form. They can adjust the patient in the wheelchair through the day, but this does not guarantee the prevention of pressure ulcers.

These pressure ulcers make the patient more susceptible to infection and there is a negative impact on the patient's quality of life. Currently there are a few solutions to this problem. These solutions can give a pressure distribution on a wheelchair seat. This distribution information can reveal points of high pressure that can lead to the formation of pressure ulcers. This can lead to better patient positioning and preventative measures.

While these solutions exist, they lack accessibility. Current solutions are incredibly expensive and targeted at researchers. This barrier prevents caregivers from using such tools. These tools also require a dedicated computer making their portability nonexistent. This makes them impossible to use in wheelchairs and impractical for caregivers.

2.0 Objective

This team is paired with Electrical Engineers, Biomedical Engineers, and Business students. The objective of this project is to design, build, and test a device to map sensor pressure maps. Our project is targeted at accessibility. Instead of being designed to be used by researchers, the target audience is the caregiver. With this in mind the CSCE team will be building a mobile application to interface with the hardware created by the Electrical and Biomedical engineering teams. This app will provide real-time data displayed using color blind formats. The app will show pressure maps from both the seat and that back of the wheelchair. Bluetooth Low Energy will be used to ensure that both the mobile device and the device on the wheelchair are power efficient. If they were not, it would negatively impact the useability of the device.

By the end of the project, we will have a prototype Android application that will allow the user to interface with a pressure sensor array placed on the wheelchair. This pressure map should help reduce pressure ulcers and improve quality of life.

3.0 Background

3.1 Key Concepts

Heatmaps are graphical representations of data usually using a gradient of color from blue to red to represent lower to higher values of data. Heatmaps can be used in a variety of ways to help visualize data collected, usually from an area of a screen, image, or sensors. A common use is to display where a user has clicked on a webpage or app.

Pressure mapping is a heatmap from the measurement of the pressure between two surfaces that are in contact. The map can be viewed both live and statically depending on how the system and user decide on displaying the data. Pressure mapping is used in medical examinations for flat feet so that they can design insoles to support the patient, improving ergonomics in bottles so that they are more comfortable and easier to handle, designing guitar bodies so that they look stylish and are still comfortable to use, and anything else that needs to be designed ergonomically.

Bluetooth transmitters are electronics that allow a non-Bluetooth device to send data to another device after it has been formatted via Bluetooth. Transmitters can be connected to devices by audio output or USB/Type-C ports. They are used to transmit sound from older and new devices that do not have Bluetooth output capabilities or send data from a computer to a mobile device.

Bluetooth Low Energy is similar to standard Bluetooth such that they can both be used to exchange data between two devices over a short range, but BLE has a considerably lower power consumption capability. Bluetooth LE stays in a sleep mode unless a connection is initiated, this makes it more ideal for devices that do not need a constant stream of data being exchanged at all times. This technology is used in health care systems like blood pressure monitoring, active wear devices like a Fitbit, and even public transportation applications.

Pulse Oximeter is a small device that measures a patient’s oxygen saturation levels. It is a painless device to use since it only needs to be clipped onto a thin part of the body, like a finger, in order to use light to measure how much oxygen is in the blood. Given the simplicity of the device it is used in many cases where the patient has a condition that may affect their blood oxygen levels like asthma or anemia.

3.2 Related Work

The Body Pressure Measurement System (BPMS) by Tekscan is a similar system to the one we desire to create. The system is a mat containing a grid of pressure sensors that allow for a pressure distribution map displayed in software with the resolution equal to the number of sensors on the mat. The Tekscan BPMS system also promises to allow for multiple mats to be used to cover larger surface areas such as beds [1]. The BPMS system is marketed for several different uses such as furniture and bed design, material testing, and seating or positioning research [1]. The sensors all allow for a 5-psi pressure range with a number of different sensor configurations that allow for different seating arrangements [1]. Our design will allow for wireless Bluetooth connection between the sensors and computer as opposed to the wired in connection that the Tekscan system offers. This will allow for more convenient usage of our device by allowing freedom of movement when monitoring and adjusting the patient in their wheelchair. Another sensor by Xsensor called the ForSite SS is a pressure system designed specifically for assisting in wheelchair seating adjustment. The mat can be set on the wheelchair and monitor how the patient is setting to aid in making adjustments to the patients seating [2]. The Xsensor pressure system also comes with an app that connects through Bluetooth that allows the user to monitor the pressure diagram of the patient's seat on the physician's tablet [2]. It has a pressure range of 0.1 - 3.87 psi as well as 5 frame/second refresh rate [2].

Xsensor ForSite SS Pressure Mat

Blue Chip Medical Products inc. has a wheelchair pressure mapping system called the MeasureX Pressure Mapping system. This is a system also designed specifically for assisting in adjusting wheelchair bound patients based on pressure point analysis. Like the other sensors there also is compatible software that comes along with the sensor pad [3]. The MeasureX system has wired in and wireless options for communication between the software and sensors. The Measure X has a larger range of up to 30 psi [3]. The BodiTrak2 Wireless IoT Pressure Mapping System is another general-purpose pressure mapping pad and software. They offer both a BodiTrak2 Pro and Lite app for PC or MacBooks and Android or iOS devices respectively [4]. The pad is marketed for multiple different applications, one of them being wheelchair users. [4]. The BodiTrak offers two resolutions of sensors one having 256 sensors and the other 1024 sensors [4]. The software displays a 2-Dimensional array of a pressure heat map similar to all the other devices.

Each of the designs listed is very similar to our proposed design. They all use a mat or pad with an array of pressure sensors that sit on the seat of a wheelchair to aid the physician in making seating adjustments for the patient. This will help prevent pressure ulcers from forming because of the patient not being seated properly. Each of the systems also has some sort of application that shows the pressure distribution map of the patient seated in the wheelchair. There are a few desired changes to our design from the ones already on the market. One is the inclusion of a continuous pressure calibration system designed by the BMEG team which makes use of a Pulse Oximeter. Another difference is the price of our system versus the other products listed. We are trying to make our design as affordable as possible with a current cost of less than $800. With the addition of the Pulse Oximeter calibration tool and the price point we will be able to design a device that has an edge over the products already offered.

4.0 Design

4.1 Requirements and/or Use Cases and/or Design Goals

Requirement (Wireless connectivity): A Bluetooth LE sensor will be used to transmit readings from the sensor array. Wired connectivity is not an option as physical wires can become entangled in the wheelchair's mechanisms.

Requirement (Companion Application): A mobile application will be used to display readings from the sensor array. This application will be developed to run on the Android operating system. It must enable the user to switch between viewing data from the seat pressure sensor array and the back pressure sensor array. The data received from the sensor array will be displayed as a heatmap.

Requirement (Sensor Array): 32 individual pressure sensors will be collected into a single sensor array, which will be used to gather pressure readings from the wheelchair user. One sensor array will be placed on the seat of the wheelchair and the other sensor array will be placed on the back of the wheelchair.

Requirement (Calibration): The companion application must provide methods for calibrating the sensor array. We will provide methods for manual and automatic calibration. The application will be manually calibrated by entering a numeric value. For automatic calibration, a caretaker will use the continuous pressure calibration system to press the patient into the wheelchair. The caretaker will then press the calibration button when the Pulse Oximeter reports hypoxic blood flow. The application will then read the pressure from the sensor array to calibrate the system.

Requirement (Accessibility): The heatmap visualizations in the companion application must be optimized for colorblind friendliness; we have chosen the Viridis colormap for this purpose [5]. As a stretch goal, we may allow the user to choose a color gradient used in the heatmap visualization.

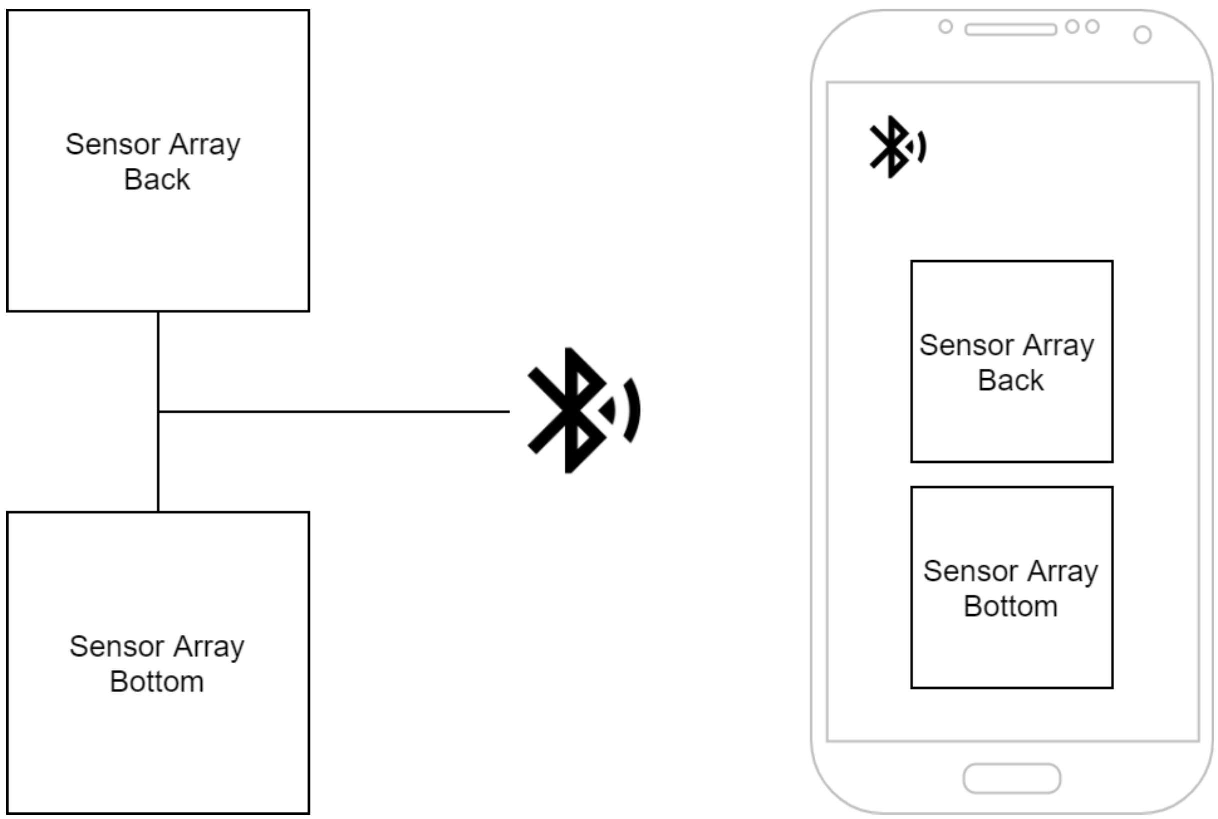
Requirement (Device Independence): The companion application must be designed to function with both a smartphone and a tablet computer, with the user interface responding to the available screen space.

4.2 High Level Architecture

Our portion of this project is the development of the application that will be used to interface with the sensors. This application is a data-visualization tool for a single type of sensor, so its focus is on effectively displaying that data for the patient's use.

Hardware Architecture

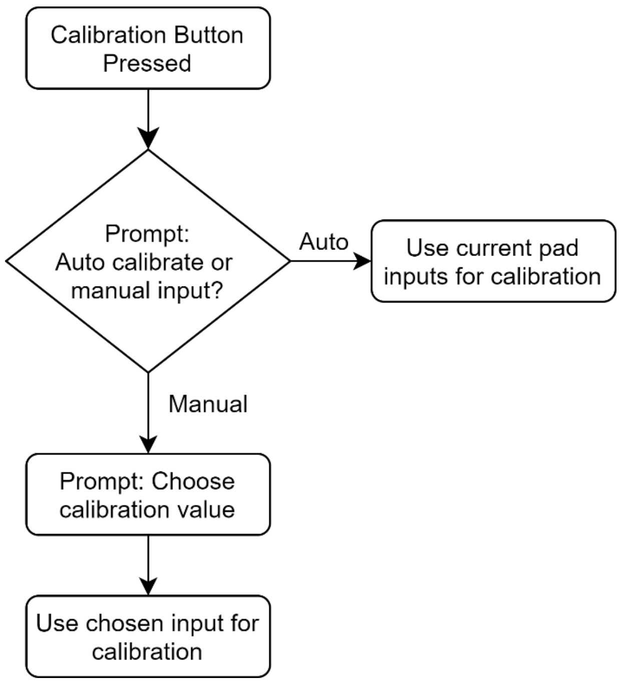
Two arrays of 32 pressure sensors will be built. One array will be placed on the seat of the wheelchair and the other placed on the back seat of the wheelchair. Both arrays are connected to a Bluetooth transmitter to send the serial data generated by the sensor array. The ELEG team will be responsible for building the sensor arrays and connecting them to a Bluetooth transmitter, so our team will work on interfacing with the Bluetooth transmitter. Figure 1 shows an overview of the hardware architecture:

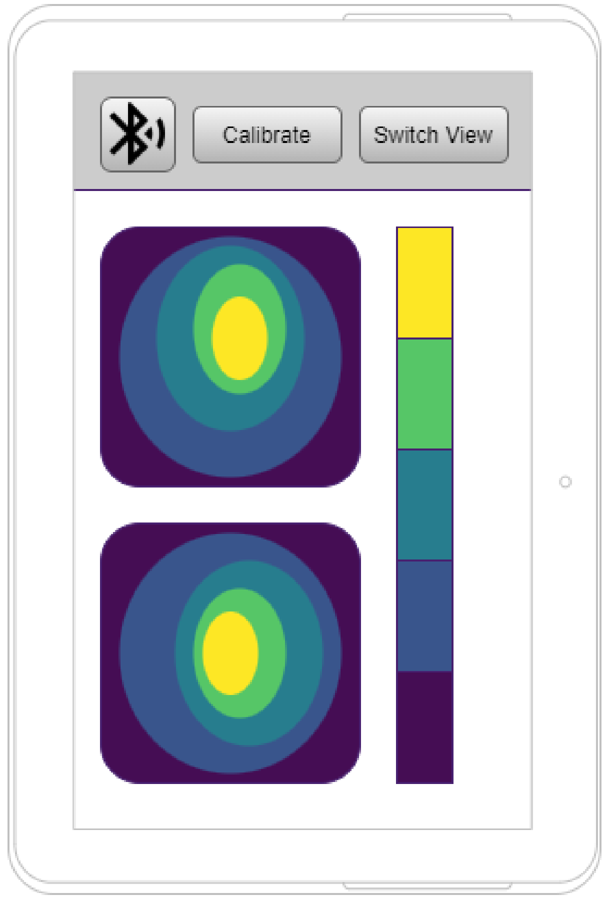


The data is sent to a companion application running on the Android operating system. This application's purpose is to expose the data generated by the pressure sensors as a heatmap to aid in making seating adjustments for better patient comfort and safety.

Application Architecture

The application will be implemented as a single-activity Android project utilizing the Model-View-Presenter architecture. The focus of the model will be to organize the data received from the sensor array for use by the view; the presenter acts as the interface between the model and the view; this architecture allows for the model and presenter logic to be reused across multiple views, which aids in the support of multiple devices and screen layouts. Figure 2 shows a mockup of the application activity:





To mitigate concerns about data storage and HIPAA compliance, the application performs all computations locally and does not store any data from the sensor. The only values it stores are:

- A calibration value, which persists calibration information across multiple runs. The user experience would be strongly degraded if re-calibration was required after closing and re-opening the application, even if the patient's position had not changed
- Connection information, which is stored to remove the need to reconnect to the Bluetooth LE transmitter upon each startup of the application. Again, this is for user-experience purposes and does not contain personal information.

Because we avoid utilizing any internet services the application is also usable in low-connectivity environments.

The application also provides a button to launch a calibration dialog. Here the user can input a calibration value determined by the current readings from the sensors and assisted by readings from a Pulse Oximeter. The calibration would set a pressure threshold for non-healthy pressure. Safe pressure values can differ on a person-by-person basis.

4.3 Risks

Risk	Risk Reduction
HIPAA compliance introduces legal complexity	The companion application does not permanently store any data received from the sensor array. With our architecture above the only information that may be saved is the calibration value and the connection information, which are not specific to any patient.
Sensor Array design is dependent on other teams	We will develop mock sensor array data that we can test the application with, for use in the event that the ELEG team is delayed in producing the prototype sensor arrays.
Creation of an iOS-compatible application would hinder progress on the prototype	We decided to only develop the application for the Android operating system to avoid duplicating effort and increasing costs on acquisition of Apple development hardware. Android was chosen because the development ecosystem is freely available, test hardware is simpler and cheaper to acquire, and because some team members already have experience developing Android applications.

4.4 Tasks

1. Verify requirements with BMEG and ELEG teams to ensure understanding across teams.
2. Write the final proposal report based on feedback given to draft proposal report.
3. *(End of Capstone I)* Create team website.
4. *(Beginning of Capstone II)* Create mock data of the sensor arrays to simulate the application without requiring the assembled sensor array
5. Build a prototype Android application to make use of mock sensor array data without a Bluetooth connection or calibration logic.
6. Create calibration logic for application and validate functionality with BMEG team.
7. Pursue accessibility goals for application (the ability to change color maps, work with screen readers, etc.).
8. Add Bluetooth connectivity to application for integration with physical sensor array.
9. Solicit feedback from BMEG and ELEG teams regarding application functionality and any required changes.
10. Implement required changes (if any) and test application.
11. Document work completed.

4.5 Schedule

Tasks	Started by	Completed by
1. Verify requirements	November 1, 2021	November 15, 2021
2. Write final proposal report	November 15, 2021	November 28, 2021
3. Create team website	November 28, 2021	December 7, 2021
4. Create mock data of the sensor arrays	November 28, 2021	January 31, 2022
5. Build a prototype Android app with mock data	January 1, 2021	February 14, 2022
6. Create calibration logic	February 1, 2021	February 28, 2022
7. Pursue accessibility goals	February 1, 2021	March 14, 2022
8. Add Bluetooth connectivity	March 1, 2021	March 28, 2022
9. Gather feedback from all teams on application functionality	March 14, 2021	April 4, 2022
10. Implement required changes (if any)	March 14, 2021	April 18, 2022
11. Document all work	March 14, 2021	April 25, 2022

4.6 Deliverables

- **Design document:** Describes and diagrams the architecture of the completed application. Also describes and diagrams the hardware components of the system.
- **Project Proposal:** Archived project proposal completed during Capstone I.
- **Project web site:** Archived project web site completed during Capstone II.
- **Android application source code:** Complete source code, build files, and layout files necessary to build and install the companion mobile application. The source code will be organized as an Android Studio project for easiest compilation and installation/emulation.
- **Final Report:** Description of work completed, additional goals contained, and an outline of possible future work.

5.0 Key Personnel

Benjamin Allen – Allen is a senior Computer Science/Computer Engineering major in the Computer Science and Computer Engineering Department at the University of Arkansas. He has completed courses in mobile application development and software engineering, along with a longstanding internship as a software engineering consultant where he has developed web servers and mobile applications. His responsibilities are focused on the development of the mobile application with a focus on the user interface.

Clay Griscom – Griscom is a Senior Computer Engineering major in the Computer Science and Computer Engineering Department at the University of Arkansas. He has completed System Synthesis and modeling and Circuits and Electronics which will help in the hardware development of the project. Responsible for aiding in the development of the communication hardware between the application and sensor array.

Hugo Serrano – Serrano is a senior Computer Science major in the Computer Science and Computer Engineering Department at the University of Arkansas. He has completed Mobile Programming and Information Retrieval which applies to this project. He is responsible for application development and UI/UX.

Kira Threlfall – Threlfall is a senior Computer Science and Pure Math major in the Computer Science and Computer Engineering Department at the University of Arkansas. She has completed Algorithms and Information Retrieval which are relevant to application development. She has been a Mobile Application Development Intern for J.B. Hunt and a Software Engineering Intern for Arvest where she learned about mobile application development and API development. Threlfall is responsible for application design and data manipulation.

David Whelan – Whelan is a senior Computer Science major in the Computer Science and Computer Engineering Department at the University of Arkansas. He has completed relevant courses. He has taken Ubiquitous and Wearable Computing and Mobile programming which directly applies to this project. He has also interned at Marshalltown Tools and Ayoka LLC where he gained experience in business process and working with large code bases. He is responsible for team coordination and Bluetooth connectivity.

Allie Burgess and Jayden Goff – During their Clinic rotations in Biomedical Engineering they both individually encountered the same problem. This problem spawned their project proposal for an accessible pressure distribution system. They both felt strongly about this project and carried it over as their senior design project in order to make it a reality.

6.0 Facilities and Equipment

We do not foresee any facilities we would need to develop this project. We will be checking out Android phones from the department in order to test the Bluetooth interface. Members of the team already have the equipment required to develop the Android platform. The Bluetooth modem used by the electrical engineers will be provided by their team to be used in the creation of the dummy device.

7.0 References

[1] Tekscan Pressure Measurement System

https://www.tekscan.com/products-solutions/systems/body-pressure-measurement-system-bpms-research

[2] Xsensor ForSite SS

https://www.xsensor.com/solutions-and-platform/csm/wheelchair-seating

[3] Blue Chip Medical Products inc. MeasureX Pressure Mapping system

https://www.bluechipmedical.com/seating-positioning/pressure-mapping-for-seating-positioning/

[4] BodiTrak2 Wireless IoT Pressure Mapping System

https://www.boditrak.com/products/medical/wheelchair.php

[5] Introduction to the viridis color maps.

https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html