GloveSight (CDR)

Navigation Assistance for the Visually Impaired

University of Massachusetts Amherst BE REVOLUTIONARY™

Team Makeup

Philip Colladay (Computer Engineering)

Jeffrey Matheson (Computer Engineering)

Anvita Patel (Computer Engineering)

Nick Viehl (Electrical Engineering)

Project Goal

To develop a glove that enables those with significant visual impairment to navigate their surroundings using haptic feedback that directly correlates with distance sensing.

Problem Statement

Visually impaired individuals primarily rely on traditional canes, guide dogs, and sighted guides in order to function in their daily lives. These solutions, among others, all have various limitations ranging from the ability to convey long distances, to being physically intrusive to the impaired individual as well as those around them. Our project aims to address these problems by integrating distance-sensing technology into a glove.

Updated System Specifications

1. Detect distances up to 6 meters from the glove with latency of < 250ms.
2. Distance measurements will be within 5% of actual distance.
3. Will non-verbally communicate distance information to the user.
    a. Minimal learning curve.
4. Have a rechargeable battery life of at least 6 hours.
    a. Will communicate low power warning to the user.
5. Will only require the use of one hand.
    a. Able to turn system on/off.
    b. Able to communicate charge level to the user upon request.
6. Be able to operate in various weather conditions (rain, fog, snow, wind).
7. Be minimally intrusive to the user.
    a. Total weight will be < 150g.
    b. Does not impede wrist rotation or hand flexibility.
8. The system should not negatively affect common pets (dogs, cats, rabbits, etc).

Hardware Block Diagram

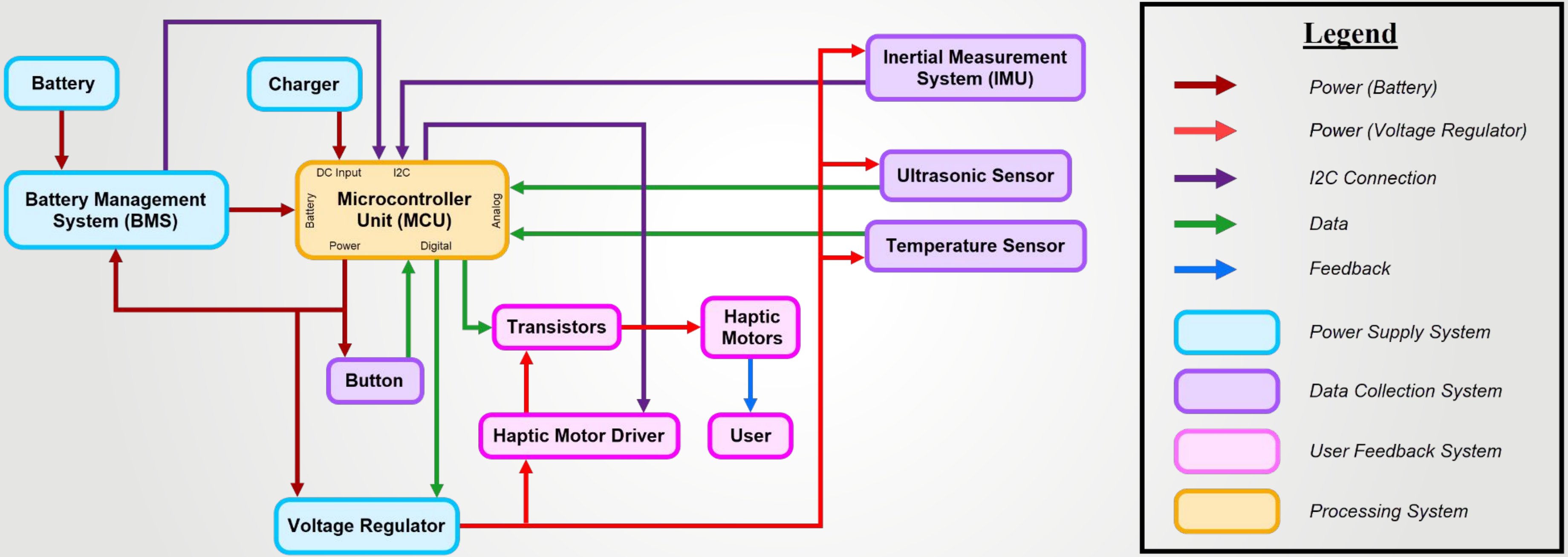


Figure 1: Our Hardware Block Diagram

Ultrasonic Sensing (MDR → CDR)

- Discovered systemic error pattern
- Pattern used to auto-correct distance after reading ultrasonic sensor data
- Improved accuracy, especially at long distances
- Will look into short distance readings improvement

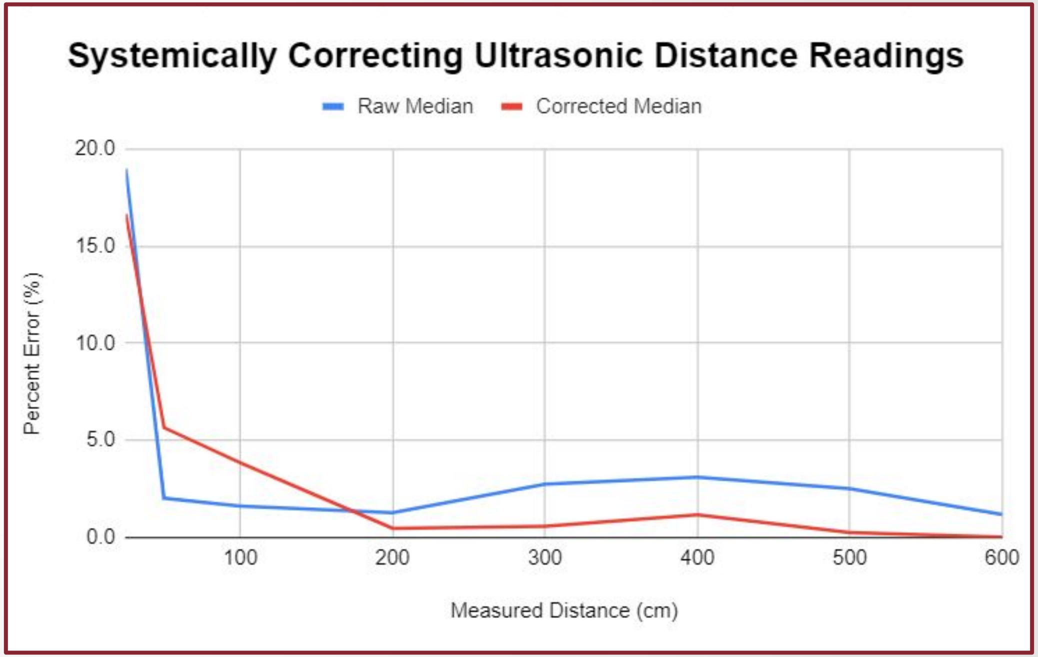


Figure 2: Correcting Systemic Distance Error

Ultrasonic Sensing (MDR → CDR) [cont.]

Implementation of two ultrasonic sensors

- Hardware:
  - Implementing second ultrasonic sensor into overall system
  - GPIO output to sensor RX to target specific sensor for a distance reading
  - BW pin connected to VCC to enable RX command
- Software:
  - To avoid ultrasonic interference: loop waits 0.1ms after each distance reading
  - To avoid ultrasonic crosswalk: 10ms pause between loops of the two sensors
  - Analyse recent distance history to determine if new reading should update communicated distance to user
  - After certain number of readings, communicated distance is updated

Ultrasonic Sensing (MDR → CDR) [cont.]

```
getDistance()
    For each Ultrasonic Sensor:
        For i in range(Samples):
            Send RX Command to Sensor 1
            read distance from ultrasonic sensor
            wait(0.1ms)
        wait(10ms)
```

Ultrasonic Sensing (MDR → CDR) [cont.]

```
chooseSensorReading()
    Std1 = standard deviation(recent ultrasonic 1 sensor readings)
    Std2 = standard deviation(recent ultrasonic 2 sensor readings)
    If difference(Std1, Std2)  = large:
        Return reading whose sensor has smaller Std
    Else:
        Return smaller distance value
```

Ultrasonic Sensing (MDR → CDR) [cont.]

```
updateDistance()
    if newDistance is outside of stdev of Recent distance readings:
        update distance being communicated to user to avg(last 5 distance
        readings)
    Count += 1
    if Count > 20:
        update distance being communicated to user to avg(last 5 distance
        readings)
```

Figure 3: Data Selection Algorithm

Ultrasonic Sensing at 30 and 45 Degree Angles

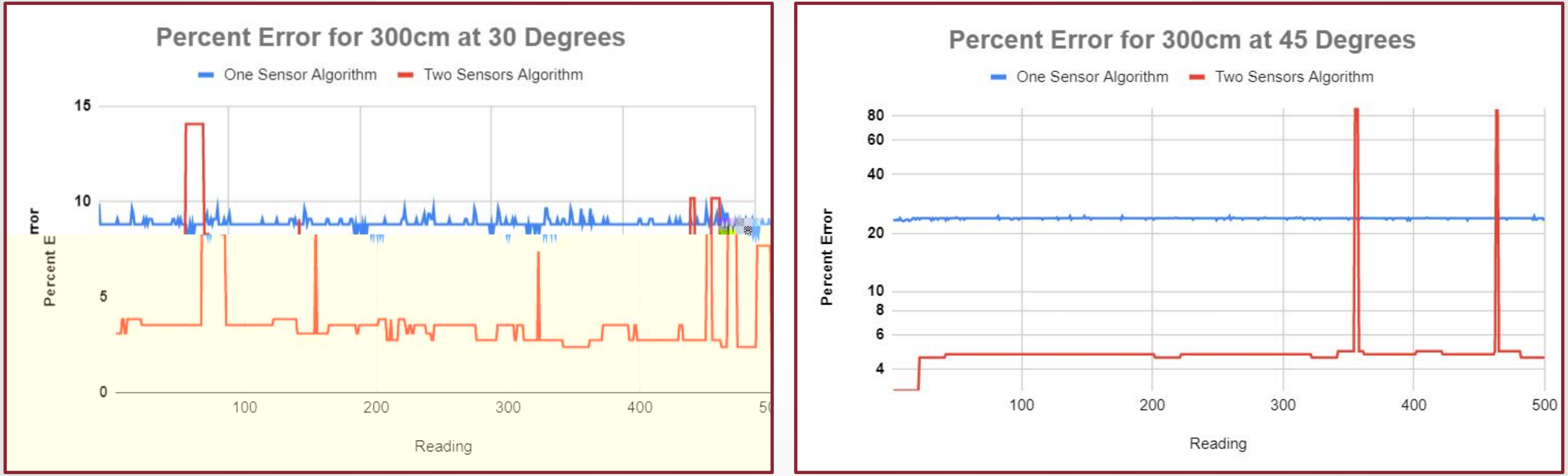
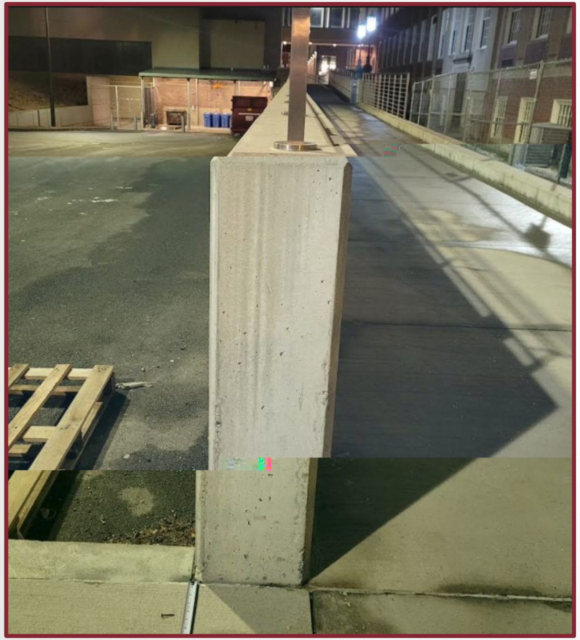


Figure 4: Ultrasonic Sensing at 30 and 45 Degree Angles

Testing on Wall Edge Setup



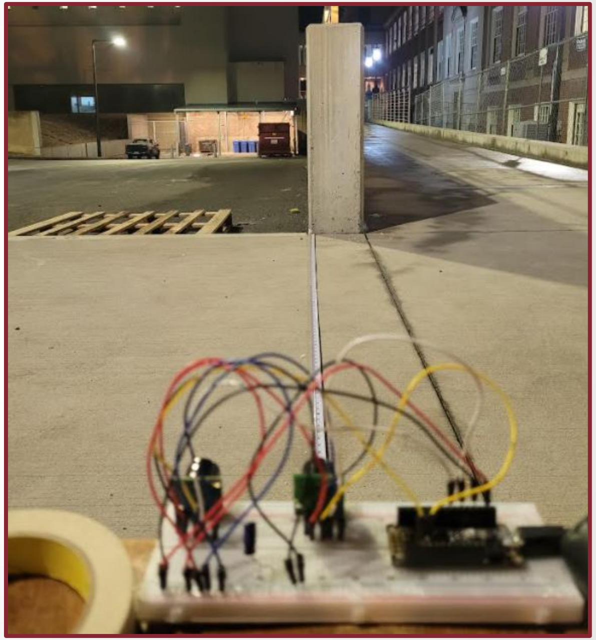


Figure 5: Edge of Wall

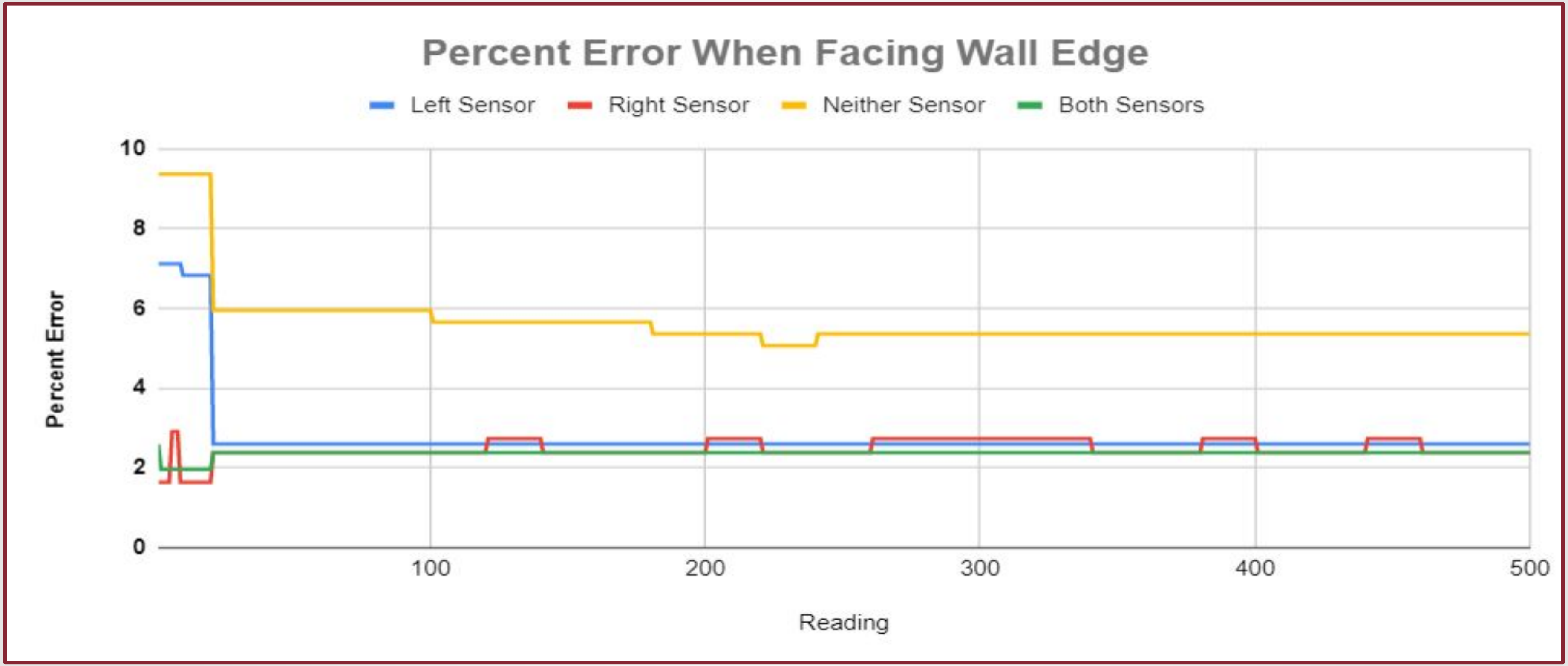


Figure 6: Percent Error at 300cm Facing Wall Edge

Testing on Various Surfaces

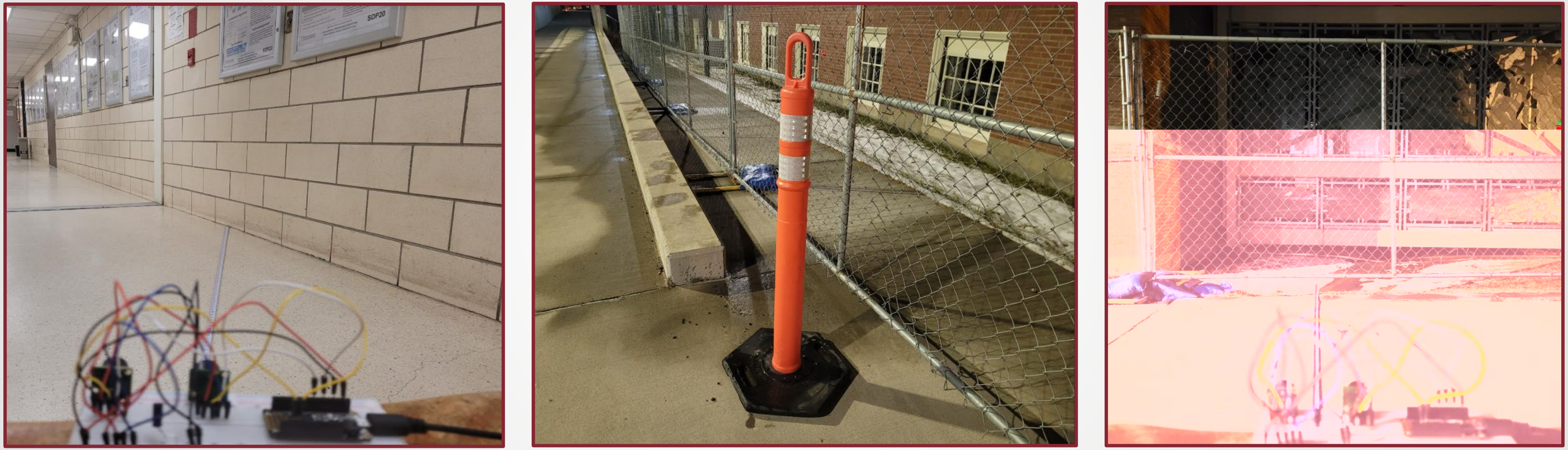


Figure 7: From Left: Wall at 30 Degree Angle, Traffic Pole, Fence

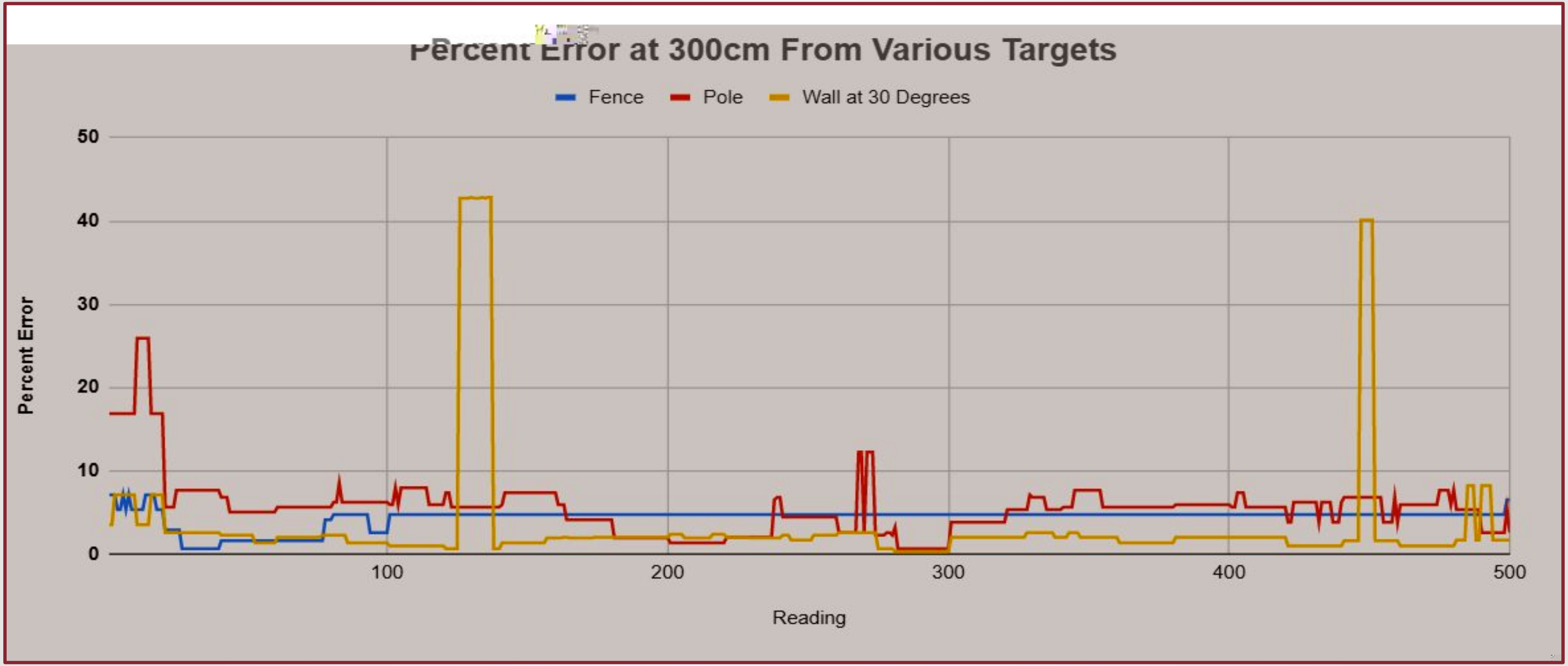


Figure 8: Percent Error at 300cm Facing Fence, Pole, Wall at 30 Degree Angle

Distance Sensing (Light-Based Alternative)

Time-of-Flight Laser Distance Measuring Sensor

- Sending out a pulse, measuring the amount of time before the pulse returns, and then converting to distance with knowledge of velocity
- Same idea as the ultrasonics, but light-based

- Allowed for a much tighter line-of-sight (3.6mm Spot Diameter @ 6m)
- Operates well over 6m (50-80m)
- Consistently accurate, even at any angle

- Unable to take continuous measurements while moving
- Inconsistent serial communication
- Lack of documentation and assistance from the manufacturer

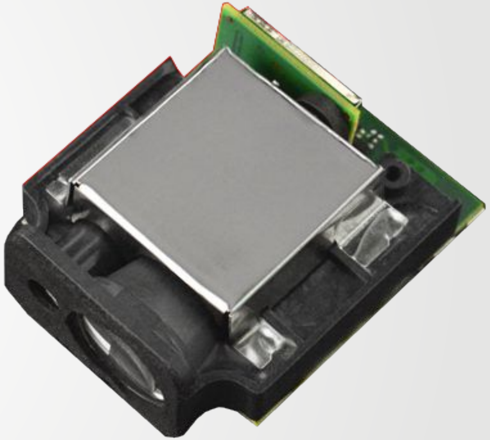


Figure 9: DFRobot SEN0366
Source: Adapted from Image [2]

Power: Energy Budget

System Component	Quantity	Voltage (V)	Current (mA)	Power (mW)	Work (µJ) (time = 6 hours)
Cortex-M4	1	Battery (3.7)	60	222	1332
Battery Management System (BMS)	1		.0045	.02	.12
Buck Converter	1	MCU (3.3)	.09	.297	1.78
Push Button	1		.00004	.0001	.0008
Ultrasonic Sensor	2	Buck Converter (3.3)	2 *(2) = 4	13.2	79.2
Eccentric Rotating Mass (ERM) Coin Motors	4		80*(4) = 320	1056	6336
Motor Controller/Driver	1		3.5	11.6	69.6
Inertial Measurement Unit (IMU)	1		4.3	14.2	85.2
Temperature Sensor	1		.006	0.02	0.12
Total			**391.9mA**	**1317.3mW**	**7904µJ**

Table 1: A layout of the system energy budget.

Power: Battery

Current Battery Characteristics

Voltage Output: 3.7V

Nominal Capacity: 2500mAh

Total Battery Life Calculation

1.

2. **>= 6.38 Hours**

Swappable Battery Concept

- Ultrasonic Sensor
  - # of Sensors
  - Better performance with 5V battery vs 3.7V battery
- Time of Flight (ToF) Sensor
  - Increase in power consumption compared to ultrasonic sensor

Figure 10: Lithium Ion Battery 3.7v 2000mAh
Source: Adapted from Image [1]

Glove Design

Overall Final Glove Design / Plan

1. **4x Haptic Motors**
   - Mounted on each finger (thumb excluded).
2. **2x Ultrasonics**
   - Mounted on the pointer and index fingers.
3. **1x PCB**
   - Mounted on the back of the wrist, with the three components connected via hinges.
4. **1x Temperature Sensor**
   - Mounted off of the PCB.
5. **1x Battery**
   - Mounted on the underside of the wrist.
6. **1x Button**
   - Mounted on the pointer finger.

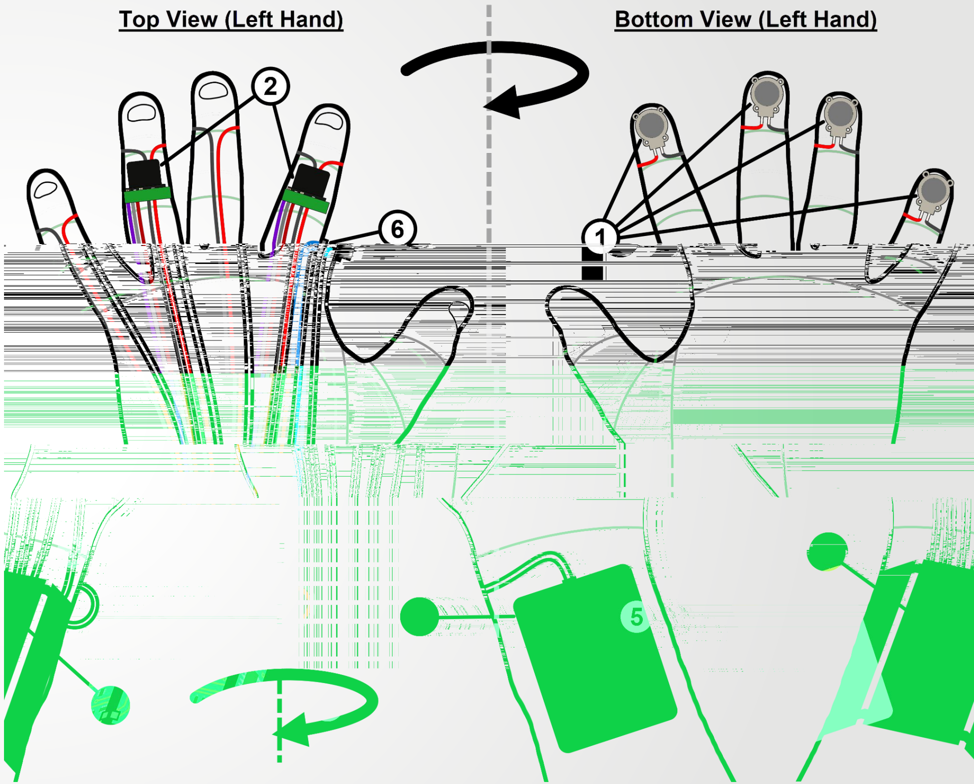


Figure 11: Final Glove Design / Plan

Glove Design [cont.]

Motor-Related Design Choices

- Motor vibration leads to the failure of thin wires, especially at the motor connection point.

- Due to the issue with the wires, pins with an added epoxy proved to be a more desirable alternative.
- Two pins wired directly to the motor terminals.

- Self-designed, 3D-printed motor casing that only adds one mm in thickness to the depth of the motor.
- The casing keeps the motor rigid and the pins fixed in place to minimize long-term damage.

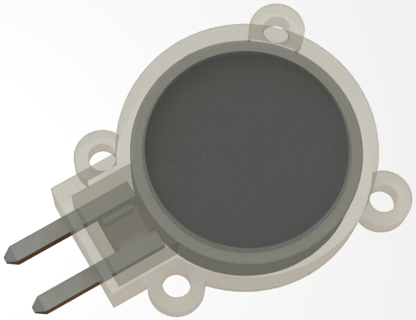


Figure 12: Updated Haptic Motor w/ Attached Pins Inside Transparent Housing

Figure 13: Updated Motor Housing

Glove Design [cont.]

PCB-Related Design Choices

- Problem
  - Combined PCB width (98mm) exceeds average wrist width (50mm)
    - **Middle Board**: 98mm by 42mm
    - **Side Boards**: 98mm by 28mm
- (1st) Solution
  - Join boards with hinges
    - **Rotational Freedom:** 180°
  - Wrap the PCB around the user’s wrist / arm in order to maximize surface area
- (2nd) Solution
  - Condense the PCB down to a single board that fits on the back of the wrist
    - Nick will discuss this further

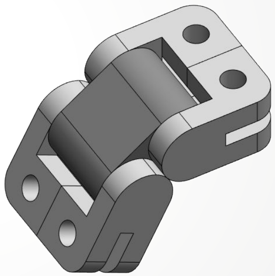


Figure 14: PCB Hinge Design

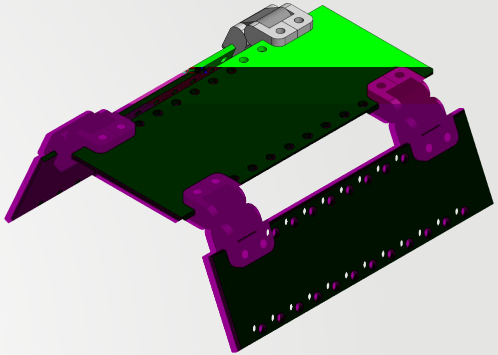


Figure 15: PCB w/ Hinges Design (Orthographic View)

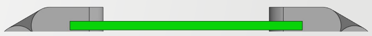


Figure 16: PCB w/ Hinges Design (Front View)

Glove Design [cont.]

Overall Final Glove Design / Plan

1. What material will the glove be made of?
    - **Elastane, Nylon, Polyester, Polyurethane, and/or Spandex**
2. How will the user put the glove on when there is a battery and PCB in the way?
    - **The arm section of the glove will use a Velcro strap and elastic material to widen the glove**
3. How do we ensure flexibility?
    - **All shifting components (mainly the wires) will be flexible and given extra slack for extending.**
4. How do we keep all components fixed in place and orientated correctly?
    - **Everything will be stitched in place and will be guided and unable to rotate, etc.**

Glove Design [cont.]

Overall Final Glove Design / Plan

- **Protruding Components**
  - Ultrasonics
    - Mounted inside of a casing
  - Temperature Sensor
    - Exposed off of the PCB
- **Top-Level Components**
  - PCB*
  - Button*
- **Bottom-Level Components**
  - Haptic Motors*
  - Battery*

*Sewn Between Glove Material Layers

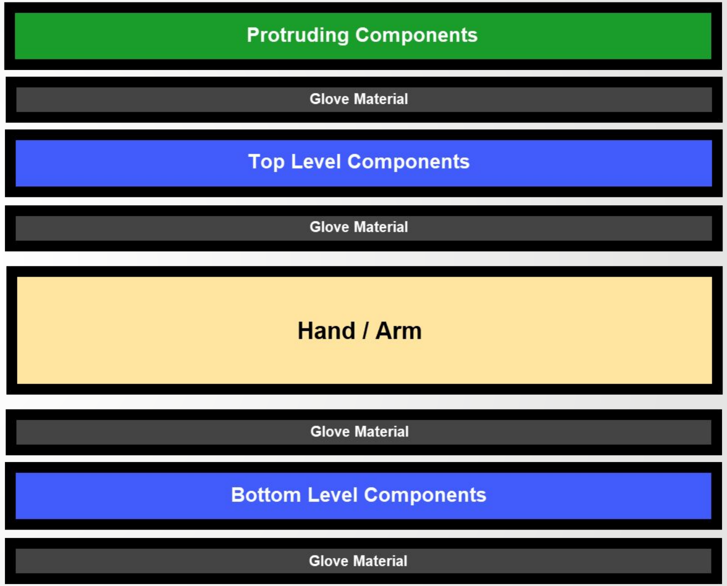


Figure 17: Glove Layering Diagram

PCB - 1st Iteration (MDR → CDR)

PCB Progress:

- Custom PCB design made to support the entire system without any (non-exempted) BOBs
- All necessary components were hand soldered onto a custom PCB
- All passive connections except for R12 are the correct footprint and are fully integrated into the board
- The push button was the wrong footprint and therefore required a temporary SMT solution
- MCU and motor driver chip was wrong footprint and has been changed for revision 2

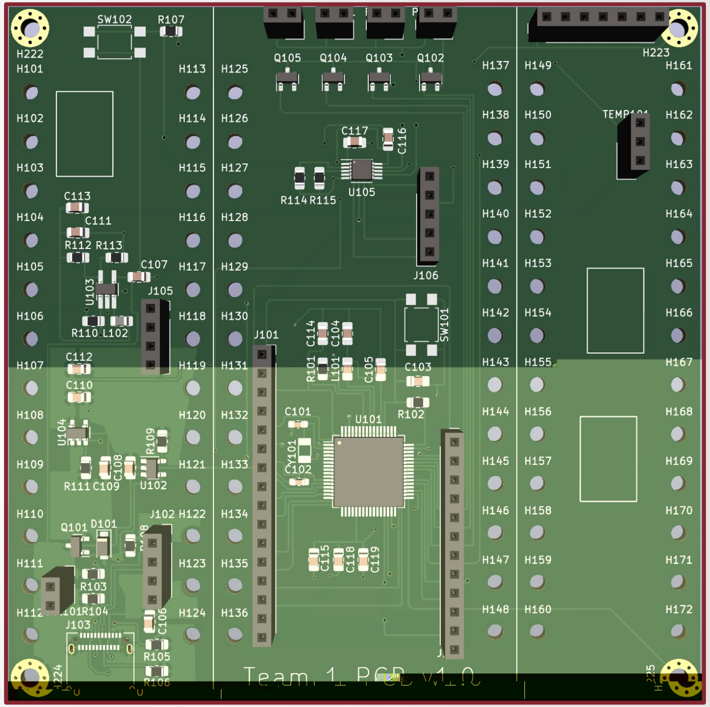


Figure 18: PCB 1st Iteration

PCB - 2nd Iteration (CDR → FPR)

Speaker: Nick Viehl

Components

- Reduce “reset button” size
- Make through hole connection for interface button
- Incorporate a second ultrasonic sensor into design
- Remove through holes for 0.254 pin receptacles

Board Structure

- Rounded edges
- Mounting points for protective housing
- Reduce overall size to roughly 40x80 mm

Circuit

- Pad entry stability
- Use more power/ground planes
- Use thicker traces
- Using 0 Ω resistors
- Add Stitching vias

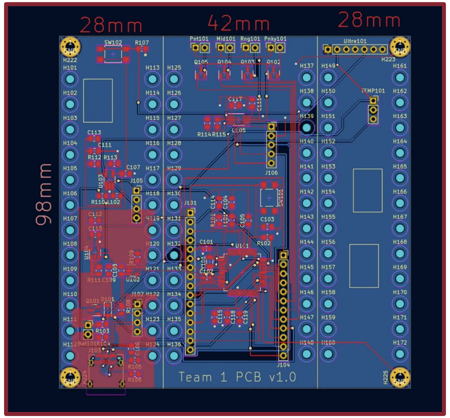


Figure 19: PCB 1st Rev

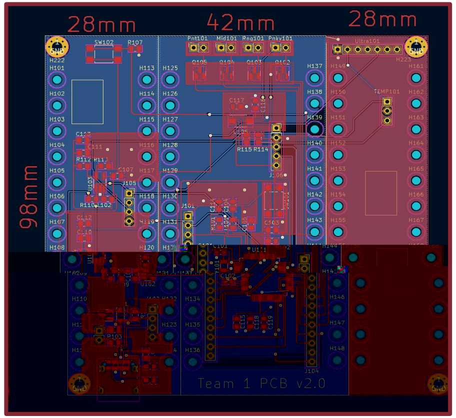


Figure 20: PCB 2nd Rev

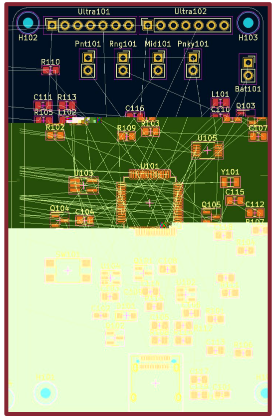


Figure 21: PCB 3rd Rev

Software Block Diagram

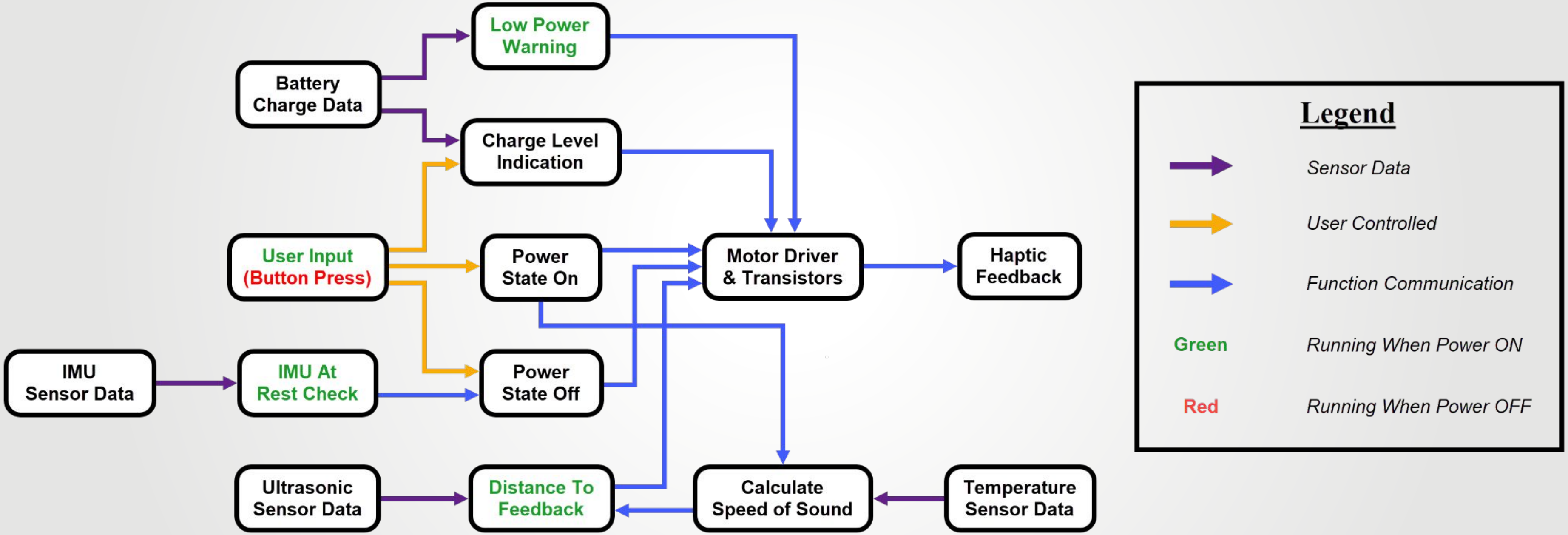


Figure 22: Our Software Block Diagram

Speaker: Anvita Patel

Software (MDR → CDR)

Conversion from Python to C

- J-Link, Atmel Studio
- Able to read analog output after configuring Analog to Digital Converter (ADC)
- Inter-Integrated Circuit (I2C)
- Digital Output
- No existing libraries for configuration of the SAMD51 chip
- Creating libraries manually for all parts of the chip (Clocks, I/O Lines, Serial Communication Interfaces (SERCOM), ADC, etc.)

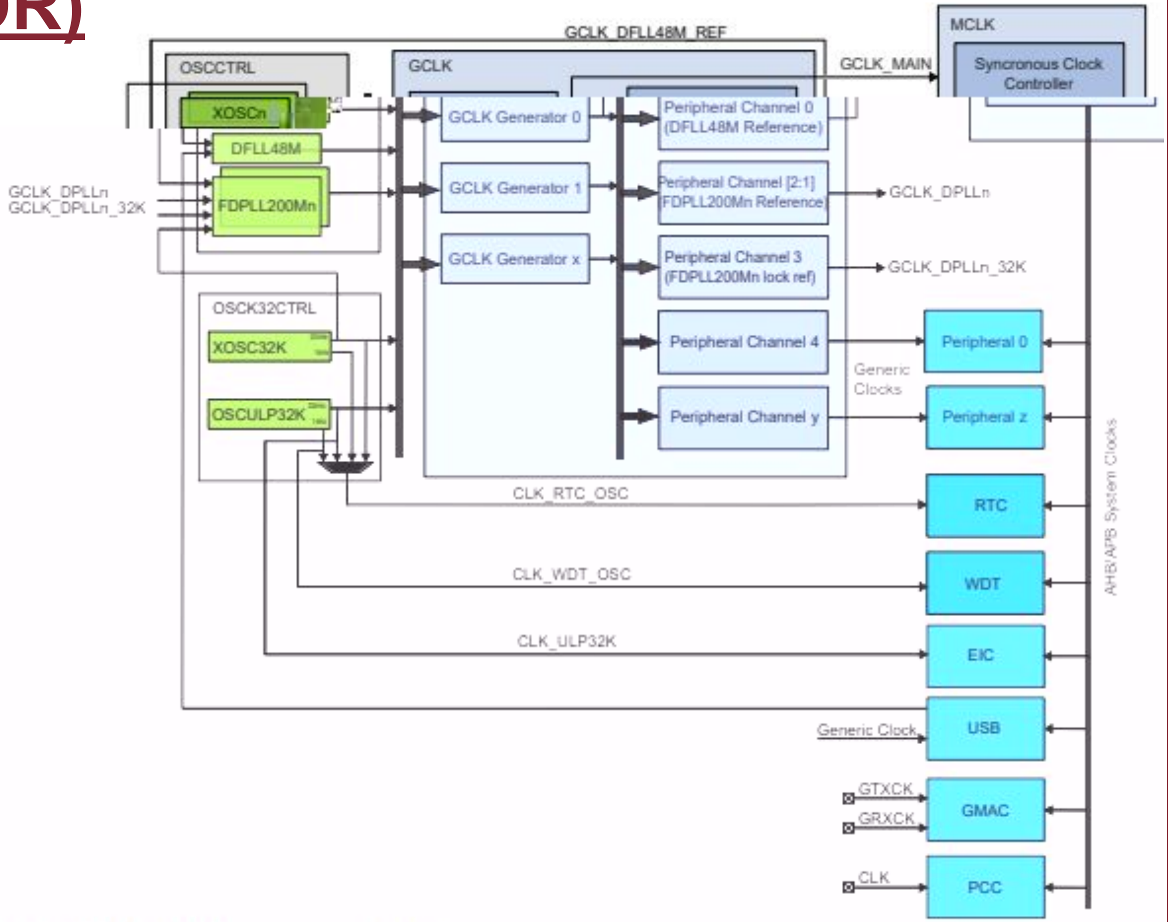


Figure 23: Clock Distribution of the SAMD51
Source: [3]

Hardware Used

Item	Quantity	Specific Part Name
Haptic Motors	4	ERM 316040001
Ultrasonic Sensors	2	LV-MaxSonar-EZ4
Power Supply	1	Lithium Ion Polymer Battery - 3.7v 2500mAh
PCB + Attached Components	1	-
Temperature Sensor	1	LMT85LPG
Tactile Switch (Push Button)	1	-

Table 2: List of Hardware Used

Current Expenditures and Weights

System Component	Quantity	Costs	
		Price of Part(s)	Shipping Costs
PCB First Revision	10	$78.16	$31.78
[BoB] Infrared Laser Distance Sensor	1	$69.90	$7.99
ERM Coin Motor	22	$26.40	$15.53
Li-Po Battery	1	$14.95	$9.02
[BoB] Motor Driver	1	$7.95	$15.53
[BoB] Buck Converter	2	$7.80	$9.02
[BoB] Battery Management System	1	$6.95	$9.02
USB LiPoly Charger	1	$5.95	$9.02
Push Button Switches	2	$1.90	$7.96
Temperature Sensor	2	$1.45	$15.53
Total Cost		**$293.69**	

Table 3: Current Expenditures Chart

System Component	Current Weight (g)
Li-Po Battery	43
PCB	32
Ultrasonic Sensors	(2) 4.3 = 8.6
ERM Coin Motors	(4) 0.9 = 3.6
Push Button Switch	0.5
Temperature Sensor	0.5
Total	**88.2g**

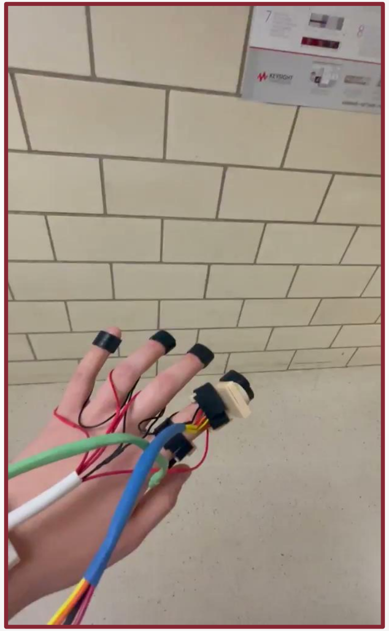
Table 4: Current Weight of the System

Projected Expenditures

System Component	Predicted Cost ($)	
	Predicted	Contingencies
Ultrasonic Sensor(s)	50	-
PCB Revisions	25	20
Final PCB Design	35	20
Glove Material	35	20
Total (Range)	**$145 - 205**	

Table 5: A layout of expected project expenditures.

Demo (Pre-Recorded Video)



Video 1: A video demonstration of the system.

Demo (Live)

Demo Layout

- Please take turns trying on the prototype skeletonized glove.

- **Distance Sensing**
  - Point the glove at various distances
  - Move closer to and further away from objects
  - Point the glove at angled surfaces
- **Button Testing**
  - Charge Indication: Press the button twice
  - Power Control: Press the button four times

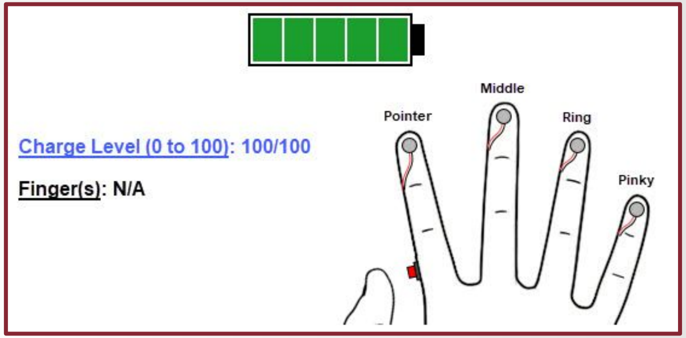


Figure 24: Charge Level Indication Diagram

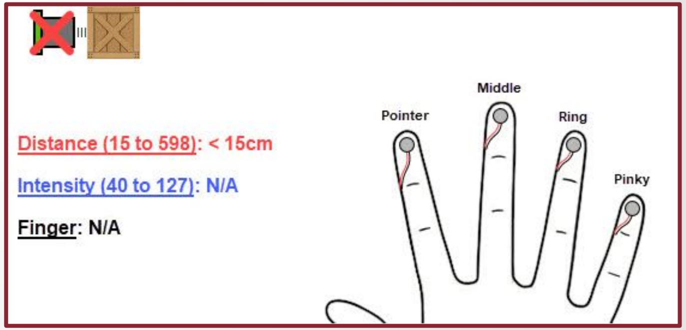


Figure 25: Distance to Feedback Diagram

MDR Deliverables Follow-Up

Legend
Completed
Nearly Completed
Not Completed

Glove Related

- *The team will have a wearable (but not necessarily finalized) version of the glove presentable for CDR*
- *Will demo the system based on the expectations of the evaluators*

User Interaction

- *The team will update the haptic response portion of the project to better reflect transitions between fingers*

PCB Related

- *The team will have the first revision of their PCB in hand for CDR, whether it is functional or not*
- *The team will populate and test the first revision of the PCB and will present on their planned second revision*

Software Related

- *The team will fully transition the code associated with their system to the C programming language*

Ultrasonic Related

- *The team will perform tests as laid out in their MDR presentation, and as requested by the evaluators*

Power Related

- *The team will include a power budget for the system in their CDR presentation*

Testing Plan

System Specification 1: Detect distances up to 6 meters from the glove with latency of < 250ms.

- **Detects distances up to 6 meters from the glove:**

  Test: Flat object will be moved at intervals of 1m between 1-6m and data will show that the ultrasonic sensors detected the object as being below 6m. Then, object will be moved to 7m and the data will still show out of range.

- **Latency of < 250ms:**

  Test: Timestamping in the program will be done before distance is sensed and after the haptic feedback is sent with a sample size of 1000.

System Specification 2: Distance measurements will be within 5% of actual distance.

- **Test:** Objects* will be moved at intervals of 1m between 1-6m and verify that sensed distance is within 5% of measured distance 90% of the time.

System Specification 3: Will non-verbally communicate distance information to the user.

- **Testing:** Simulate distances from 15-598cm and record the intensity of the particular motor at intervals of 5cm. The intensity will be correct at least 90% of the time.
- **Demonstration:** Show that the right motor buzzes at distances of intervals 1m, 2m, 3m, 4m, 5m, 5.98cm.

Testing Plan [cont.]

System Specification 4: Have a rechargeable battery life of at least 6 hours.

- **Battery life of at least 6 hours:**

  Test: Continuously cycle through motors each running at 100% intensity for one minute, continuously read all sensors for 6 hours. Record battery percentage at intervals of one hour and show that it is not at 0% at 6 hours.

- **Communicates low power warning to user:**

  Demonstration: Set the percentage of battery at 22% in the program and verify that the low power warning automatically alerts the user at 20%.

System Specification 5: Will only require the use of one hand.

- **Able to turn system on/off:**

  Demonstration: Press button 4 times while system is off, and all motors will vibrate for a few seconds to show system is turned on. Then, press button 4 times while system is on, and no motors will vibrate to show system is turned off.

- **Communicates charge level to the user upon request:**

  Demonstration: Set the percentage of battery between 15-85% at intervals of 20% in the program. Press the button twice for each percentage and verify that the motor(s) corresponding to the correct finger(s) will vibrate.

Testing Plan [cont.]

System Specification 6: Be able to operate in various weather conditions (rain, fog, snow, wind).

- **Test:** Take system in weather conditions of rain, snow, and wind for 15 minutes (fog as well if weather permits). The system will be able to operate within the specifications.

System Specification 7: Be minimally intrusive to the user.

- **Total weight will be < 150g:**

  Test: Check total weight of the system on a scale.

- **Does not impede wrist rotation or hand flexibility:**

  Demonstration: System will be worn by multiple people and surveyed on if their hand is able to move freely.

System Specification 8: The system should not negatively affect common pets (dogs, cats, rabbits, etc).

- **Research:** Due to ethical reasons, this specification will not be tested. Instead, applicable research will be cited to show that distance sensors do not affect common pets.

FPR Plan

General

- **Distance Sensing Algorithm:** Finalize algorithm for distance sensing to optimize and balance accuracy, consistency, and latency.
- **Haptic Feedback:** Test and fix any intensity divergences and physical reliability of motors.
- **Completed Conversion of System Code From Python to C**

- **Finalized PCB:** Order second revision (potentially third) and integrate into the system.
- **Finalized Glove**
- **Total Glove Cost Table**

Demo

- **Evaluators will wear fully designed glove**

- **Evaluators will be able to interpret distance through haptic feedback**

Gantt Chart (Post-CDR Until FPR)

#	Task Name	Start Date	End Date	Members	Weeks 29	30	31	32	33	34
Hardware										
1	Finalization of Glove Design	3/14/22	4/8/22	[J.M.]						
2	PCB 2nd Revision	3/14/22	3/25/22	[N.V] & J.M						
3	PCB Finalization	3/28/22	4/8/22	[N.V] & J.M						
4	FPR System Preparation	4/11/22	4/22/22	[J.M] & All						
Software										
5	Finalization of User Interaction Code	3/14/22	4/8/22	[J.M]						
6	Distance Sensing Finalization	3/14/22	4/1/22	[P.C]						
7	Overall Code Finalization	3/14/22	4/8/22	[A.P] & P.C						
8	FPR System Preperation	4/11/22	4/22/22	[J.M] & All						

Table 6: Gantt Chart (Post-CDR to FPR)

Team Member Responsibilities

Philip Colladay

- Data Processing Lead: Will finalize the ultrasonics / general distance measurement system and assist Anvita with the C code conversion.

Jeffrey Matheson

- Team Coordinator: Responsible for coordination among the team members and with our advisor / evaluators.
- User Interaction Lead: Will finalize the haptic system as well as finalize the overall glove component of the project.

Anvita Patel

- Budget Lead: Coordinates the purchases associated with the project and ensures that they are appropriate.
- Programming Lead: Will finalize the conversion to C code.

Nick Viehl

- PCB Lead: Will finalize the PCB design (both the 2nd and potential 3rd iteration).
- Component Integration Lead: Will ensure all components are functional and communicating as intended.

Image Citations

[1] "Li-Polymer Battery Technology Specification - Adafruit Industries." [Online]. Available: https://cdn-shop.adafruit.com/product-files/328/LP785060+2500mAh+3.7V+20190510.pdf. [Accessed: 2-Dec-2021].

[2] "Infrared Laser Distance Sensor (50m/80m)" [Online]. Available: https://dfimg.dfrobot.com/store/data/SEN0366/SEN0366.jpg?imageView2/1/w/564/h/376 [Accessed: 3-Mar-2022].

[3] "Clock Distribution" [Online]. Available: https://www.microchip.com/en-us/product/ATSAMD51N19A [Accessed: 7-Mar-2022].

Questions / Answers Session