SDP 24 Team 30 - FPR

Haptic Vision

A navigation system for the visually impaired

Team

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https://www.iapb.org/learn/vision-atlas/magnitude-and-projections/projected-change/

Problem Statement

Visually impaired individuals encounter substantial hurdles in navigating changing environments, as obstacles beyond their immediate surroundings remain invisible to them. Current solution using walking canes are limited in range, and need for a solution involving greater detection range is ever prevalent.

https://www.iapb.org/learn/vision-atlas/magnitude-and-projections/projected-change/

Our solution - “Haptic Vision”

A human centered device that identifies obstacles using Time of Flight sensors and alerts users through haptic feedback, providing a high level of spatial awareness.

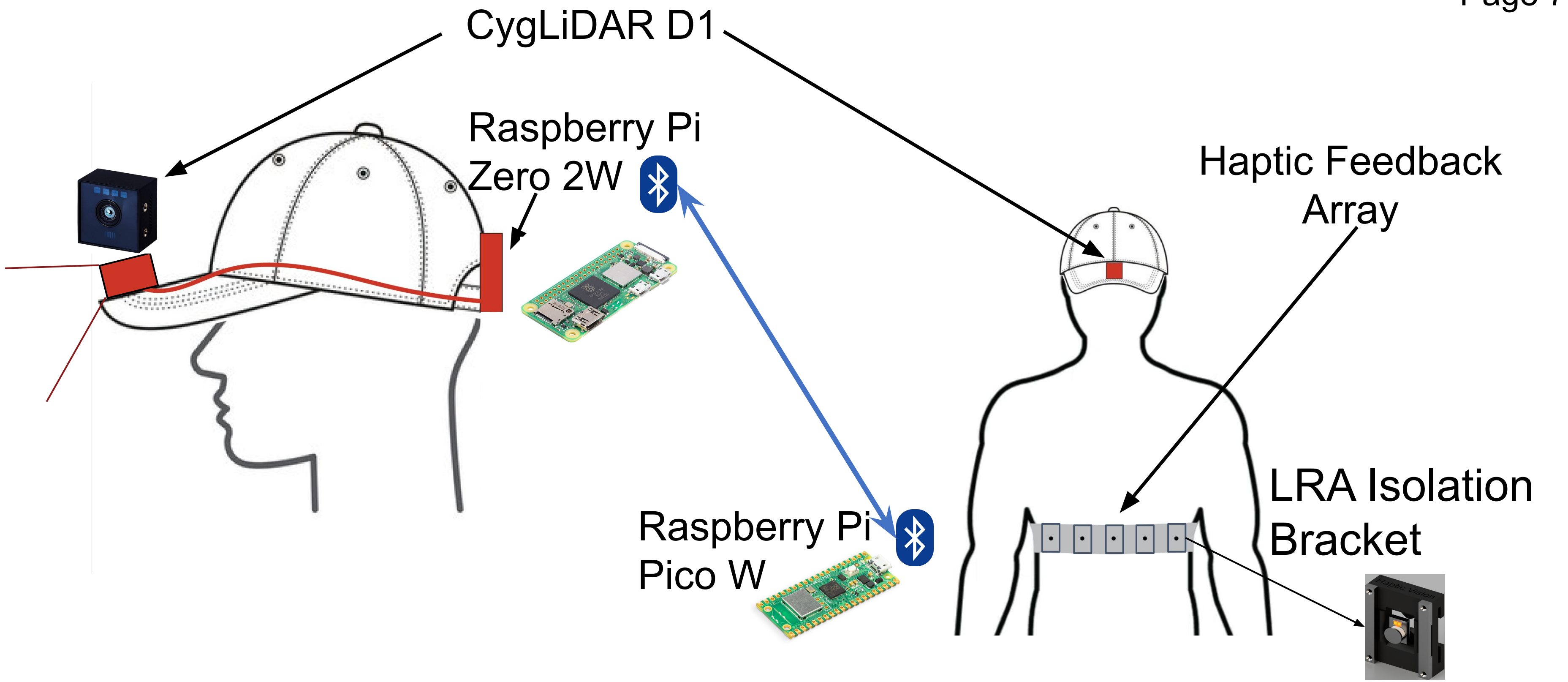
The system will have two main parts:

- Sensors attached to headwear
- Haptics on chest band

Goals

- Early warning in dynamic environments
  - Parking lot, sidewalk, grocery stores, etc.
- System functionality in low light environment
- The system should not impede users' mobility

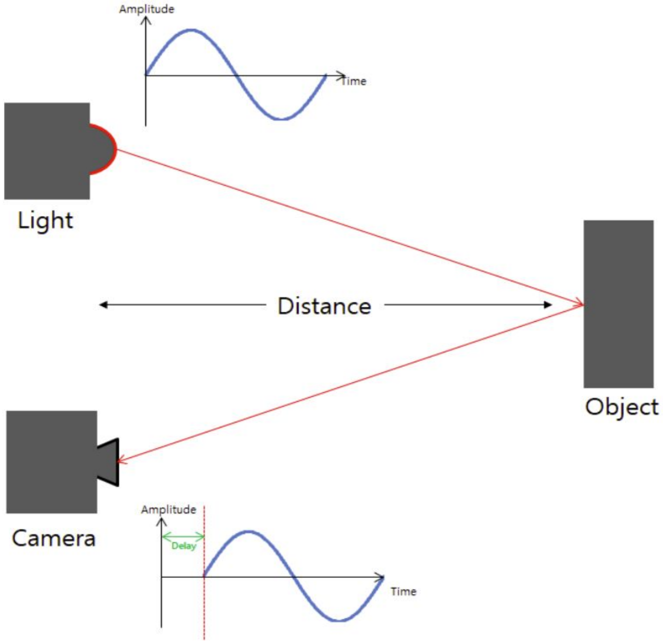
Design Overview



Critical Design Decision - LiDAR

Distance Sensor selection and head placement:

- CygLiDAR solid state chosen over other ToF sensors due to high resolution and package size.
- Single distance sensor selected to reduce weight and size for head mounted components.
- Sensor mounted on head allows for user to scan multiple directions without have to rotate entire body.



CygLiDAR D1 uses phase shift to calculate distance to objects

Critical Design Decision - Haptic Band

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Haptic band lower chest placement:

- Large circumference to spread multiple vibration units evenly to distinguish direction of obstacle.
- Allows for easier/quicker doning of single haptic band as opposed to multiple arm/leg bands.
- Multiple other designers choose this position.
    - Active Belt[1], MIT ALVU[2]

[1]ActiveBelt paper link Click Here
[2]MIT ALVU paper link Click Here

Quantitative Test Plan

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System Specification	Test Plan	Results
System will be able to detect obstacles from <=6ft.	Get distance to print on terminal, manually measure distance.	Serial port measurements are accurate to physical measurements.
System will give different haptic feedback for different ranges: - Single click: 6’ ≥ range > 4’ - Double click: 4’ ≥ range > 2’ - Triple click: 2’ ≥ range > 0’	Observe LRA clicks at the three different range regions.	Haptic clicks operating as expected, between 1-3 clicks depending on range. Also viewable with LEDs.
Each system is guaranteed to maintain power for a minimum duration of at least 5 hours.	Measure current of both systems under normal operating conditions.	Haptic belt can run for over ~12.5 hours. Headgear can run for ~7.6 hours.
The 5 LRAs in the haptic system will activate when object is detected on each angle group on a 120 degree angle.	Measure and inspect each angle group's detection using protractor.	Each zone had 24 degrees of vision ±5。

Qualitative Test Plan

System Specification	Test Plan
System will begin to work upon power up.	Inspect that system is functional upon power up.
System is designed for straightforward and hassle-free setup.	Survey 10 people with setup, ask to rate on a scale of 1-10 complexity of setup.
System will have low light capabilities.	Inspect that the system is functional at night.
Communicate obstacle distance and direction to the user, through haptic feedback.	Inspect haptic feedback through obstacles from different angles and distances.
The haptic feedback must be recognizable by the user even when they are distracted.	Survey 10 people with setup, ask to rate on a scale of 1-10 if they recognize the feedback.
System will allow user to manipulate distance and strength of the LRA.	Inspect that the distance threshold has decreased upon pressing button1 and that the strength of the LRA changes upon pressing button2.

Security Threats

- **Threat vectors**
  - Replay, injection, via bluetooth messages
  - Taking control of haptic via connecting to BT device first
  - Physical attack, Injection
    - Not feasible, as it cost more to attack
- **Solutions**
  - Add XOR encryption to the BT messages before sending message
    - Receiver decrypts using shared key.
  - Authenticate the device being connected using MAC address
    - If not allowed MAC address, disconnect

CDR Challenges

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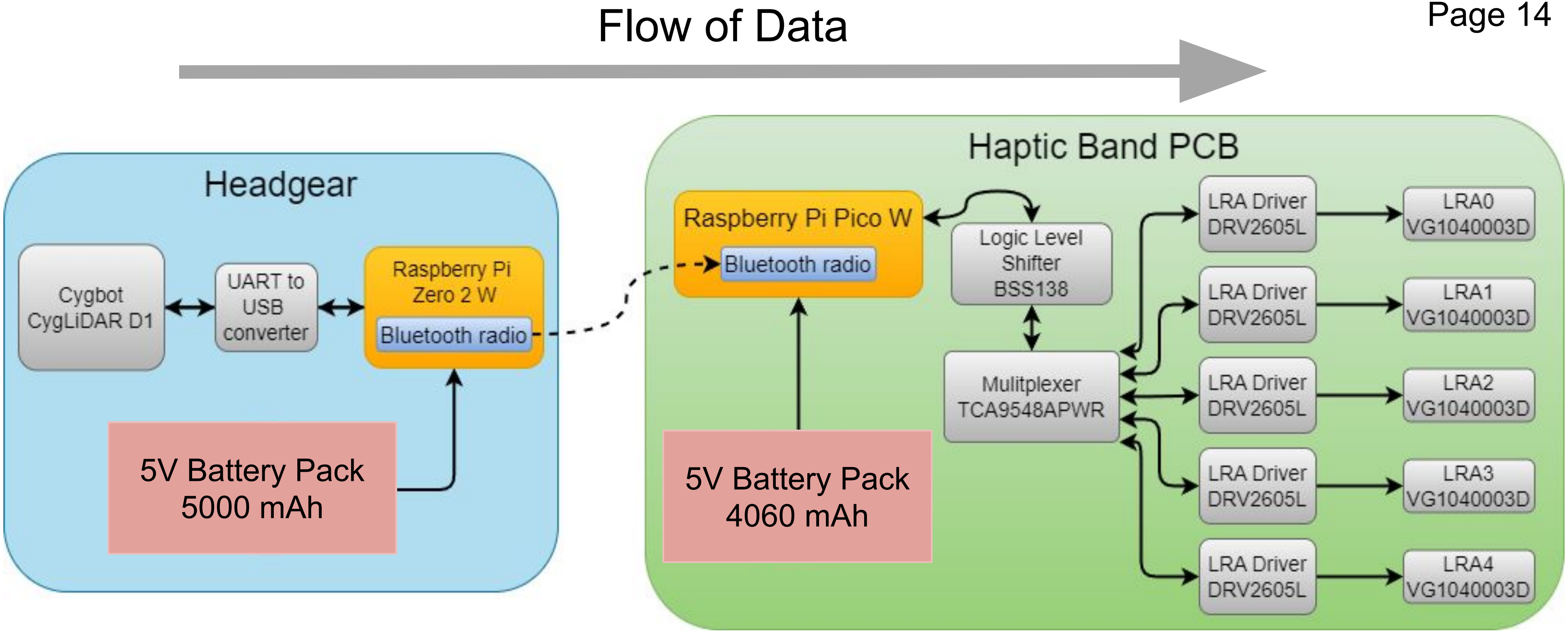
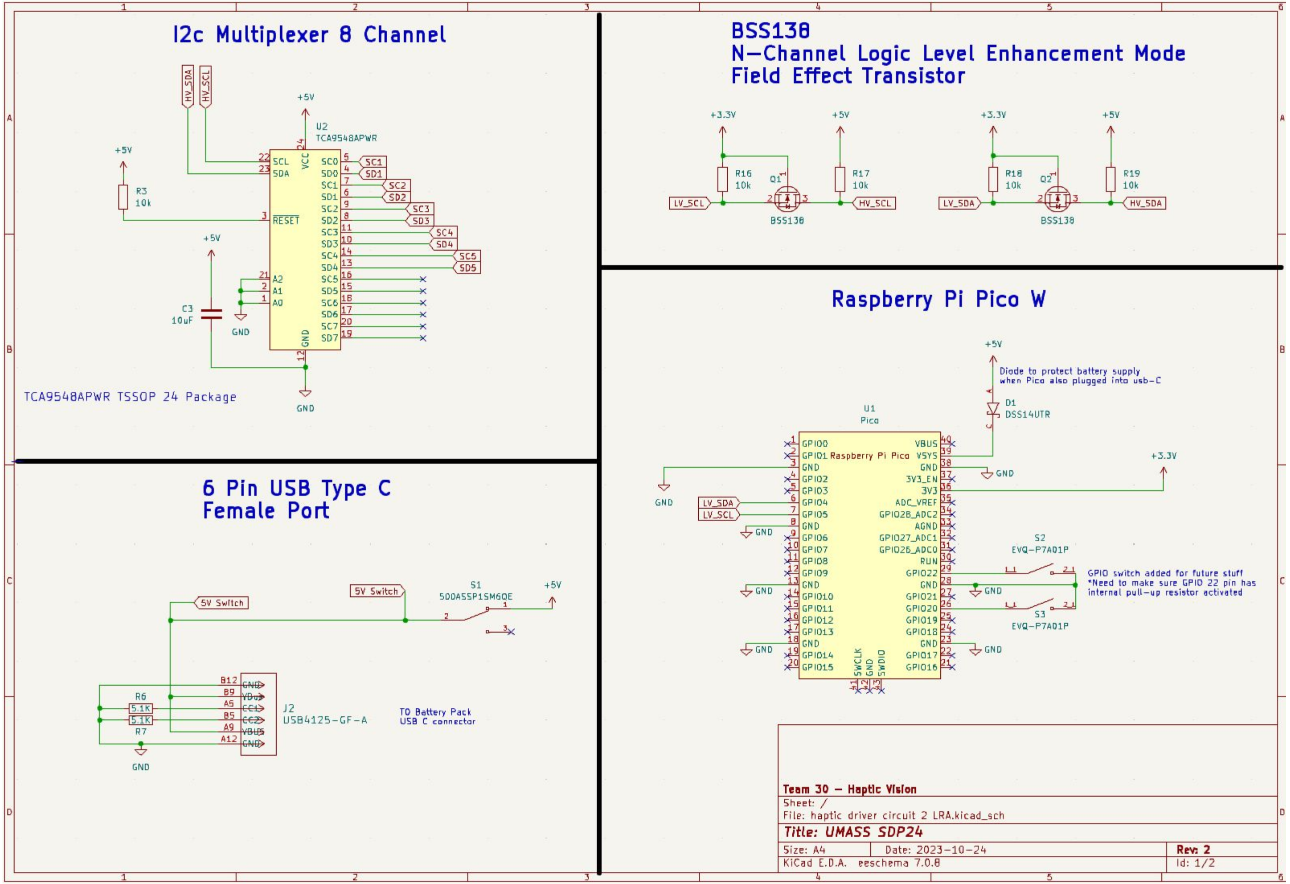
- Module compatibility and debugging of the modules themselves. The modules that our team will be using are not something our team has experience with prior to SDP.
- Limited processing power of single board computers.
    - Certain cutbacks and optimization is necessary for RPI Zero 2W to run with acceptable performance

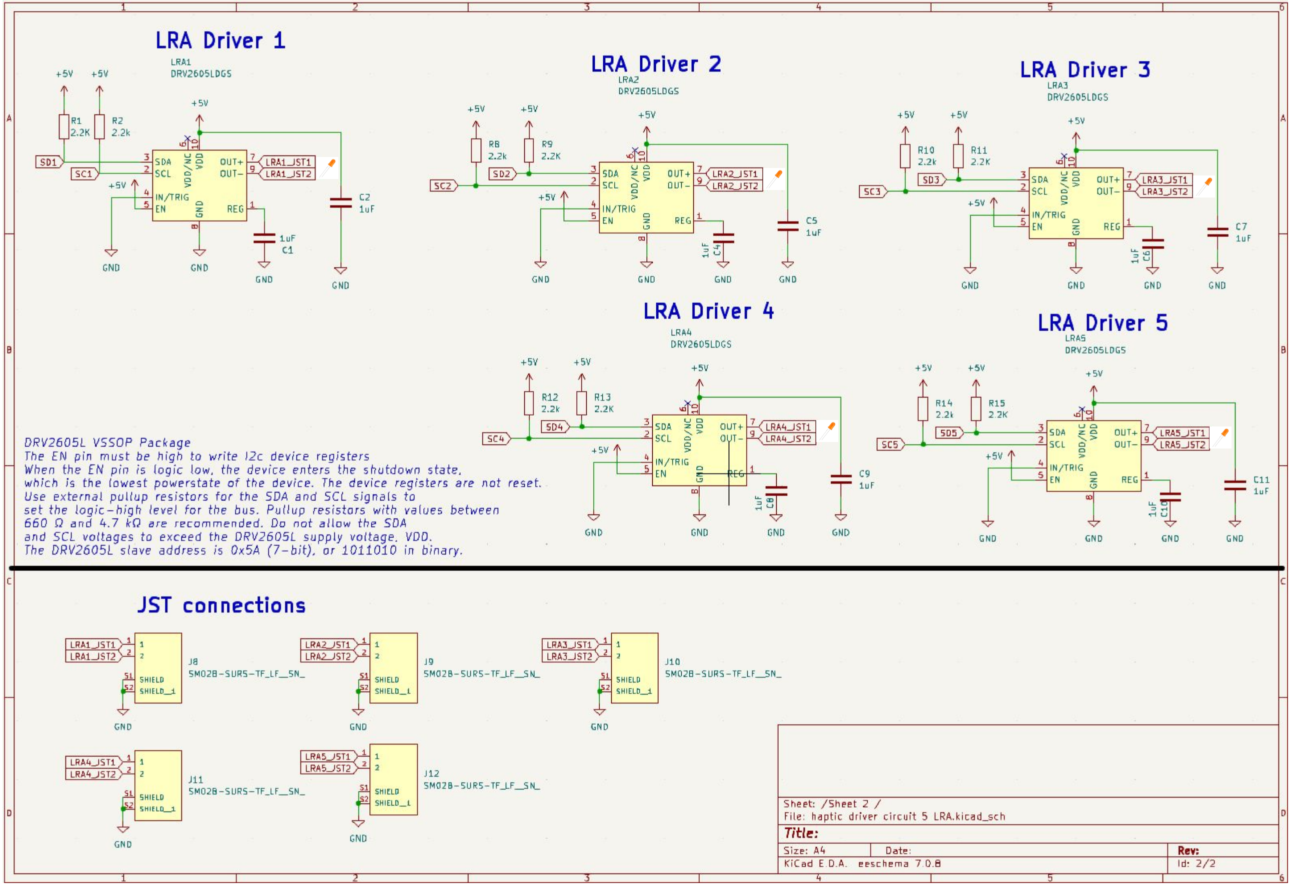
Hardware Block Diagram



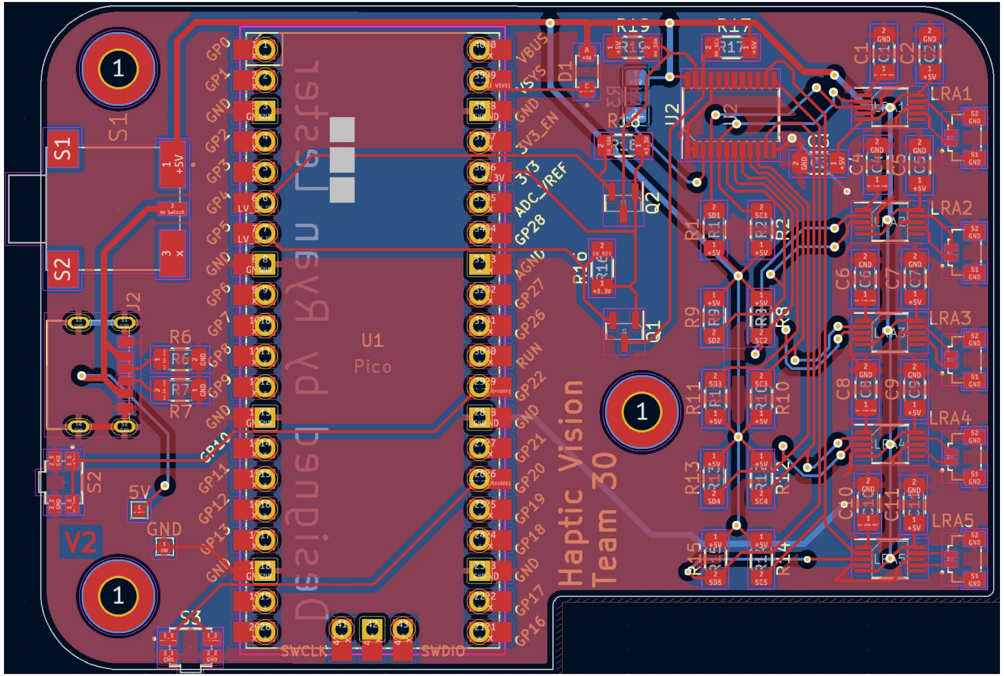
PCB V2 Design - Schematic



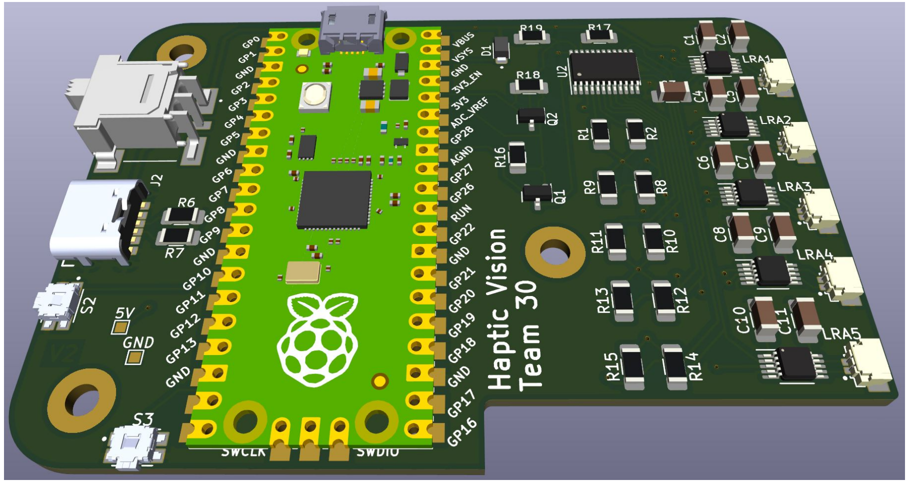
PCB V2 Design - Schematic



PCB Design - Layout



KiCAD PCB Layout view



KiCAD 3D view

Hardware - Haptic Feedback

LRA (Linear Resonant Actuator)

Electromechanical devices that vibrate to provide tactile feedback.

Vybronics - VLV101040A

- 2.75 Grms vibration strength
- 10ms rise/40ms fall times

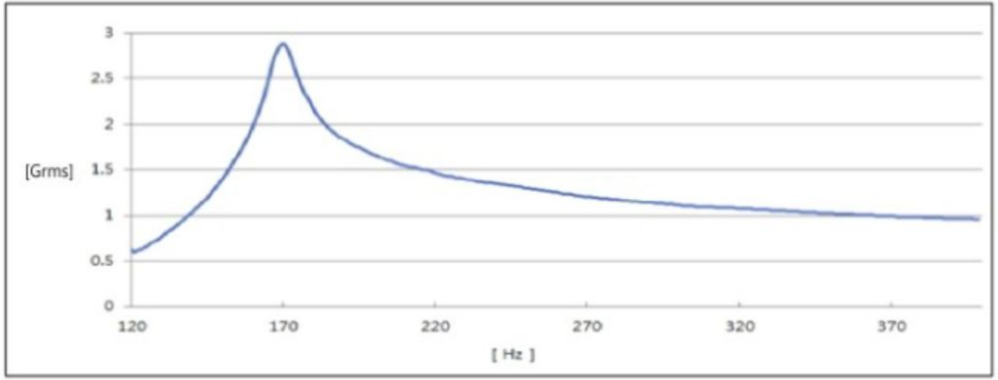
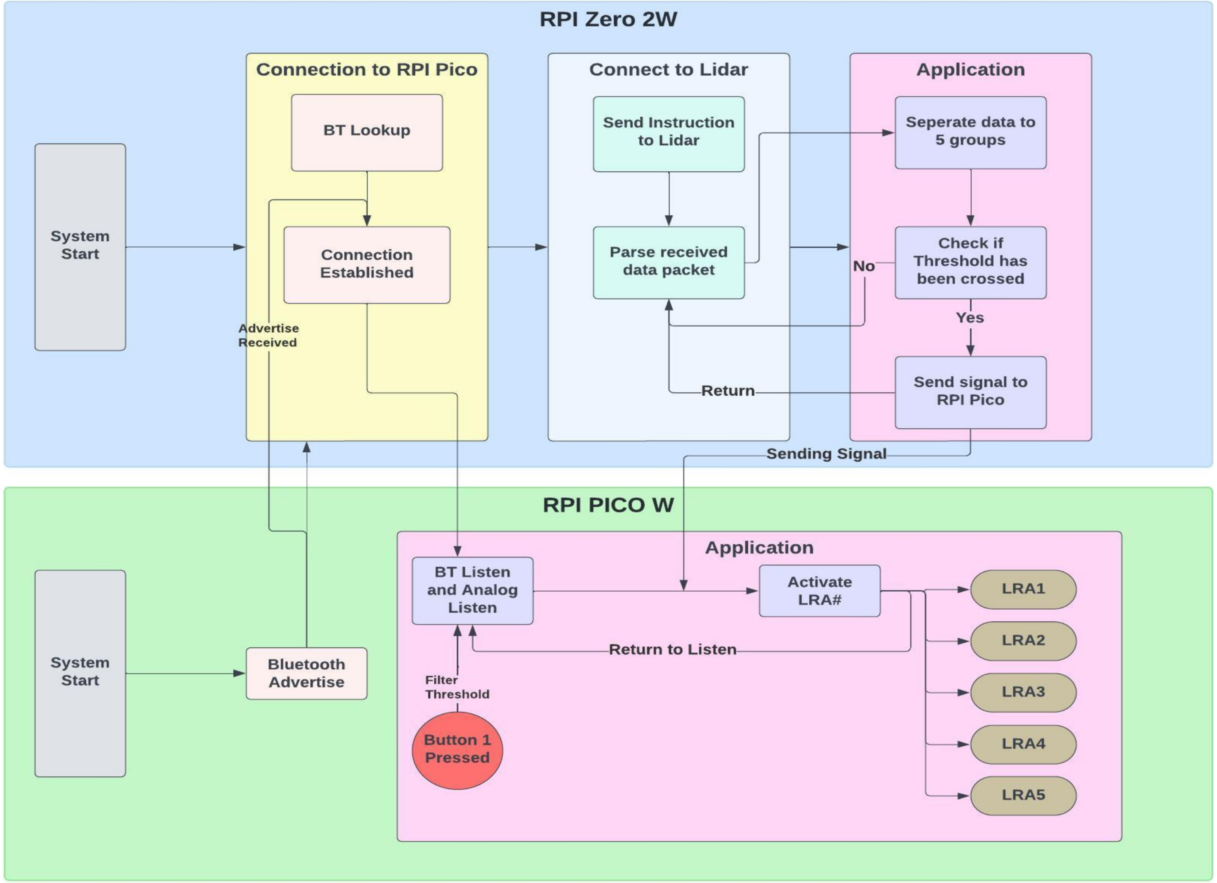


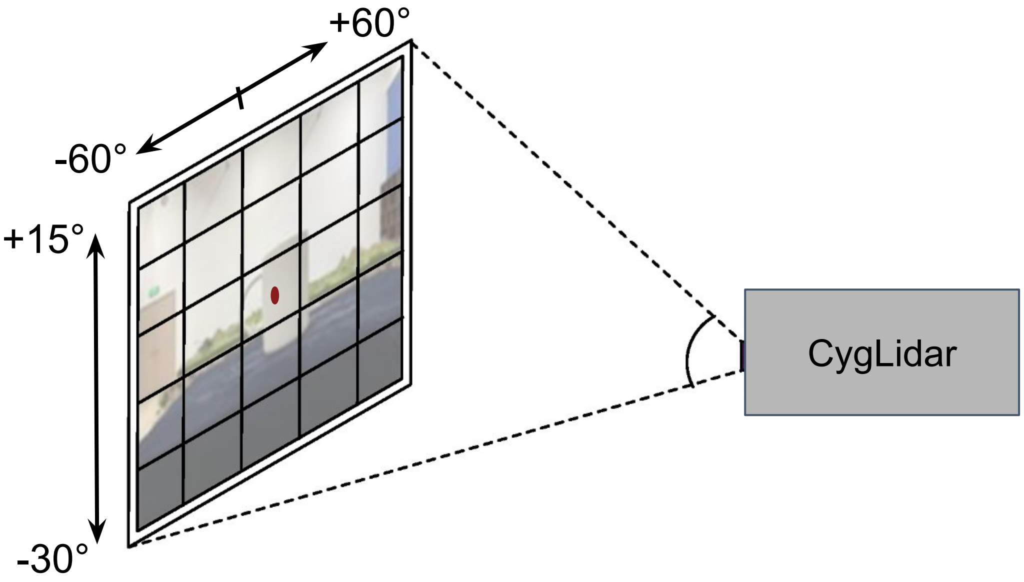
Figure 2. Frequency Characteristics

Software Diagram



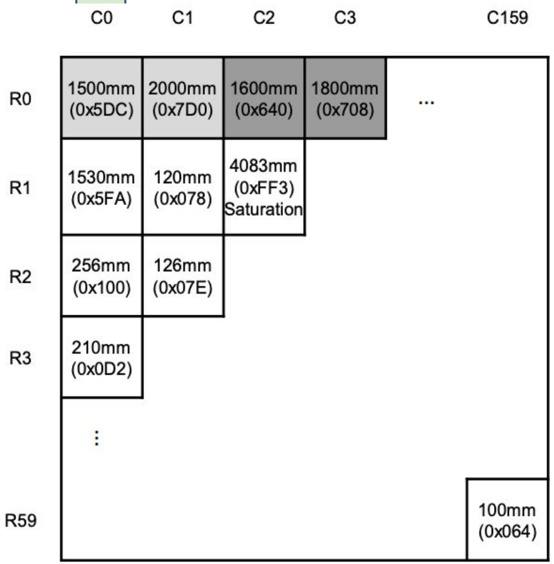
Spatial Coverage

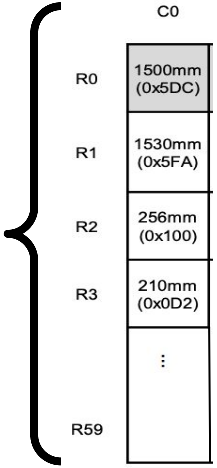
- Vertical -30° to +15°
  - Ceiling and floor
- Horizontal -60° to +60°
  - Full coverage



Algorithm

Average each column

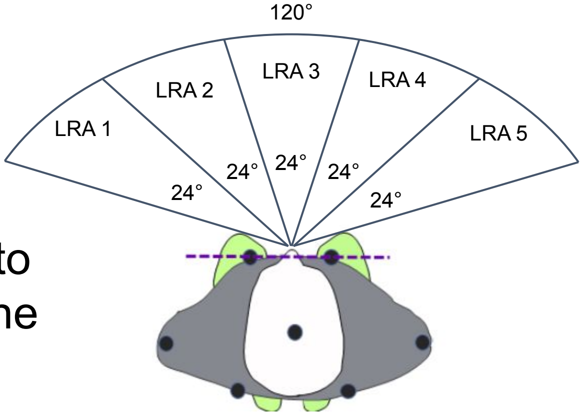




3 Min values from columns grouped together into 5 zones, averaged, then checked if threshold has been crossed

({C0, C1, C2, … ,C31}, {C31, …, C63}, … , { … , C159})

Each group correlates to one of the 5 LRAs on the chest band



Button Functions

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2 Button cycles

- Input
- Second mode ignores signals from 4 feet and beyond

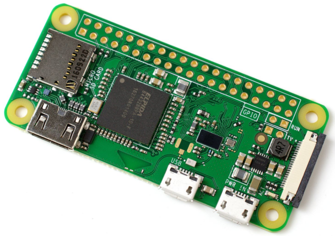
Purpose

- Allow user to change mode depending on their surroundings

Bluetooth Capabilities

Raspberry Pi Zero 2W

- Connects to the specific MAC address of the Pico W
- Sends data to activate specific LRAs



Raspberry Pi Pico W

- Advertises Bluetooth Signal
- Receives data from Zero to activate LRAs
- Initializes LRA drivers

Transition from Python to Pypy Interpreter

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Pypy3

- On paper, 4.7 times faster than regular Cpython interpreter.
- Highly compatible with python codes
- Utilizes JIT compiling, which is faster than AOT compiling

Goal

- Latency sub 2 seconds
- Initial Python interpreter latency
  - 3.2s latency
- Pypy3 interpreter latency
  - Result= 1.87s Latency
    - Goal achieved

Latency Study

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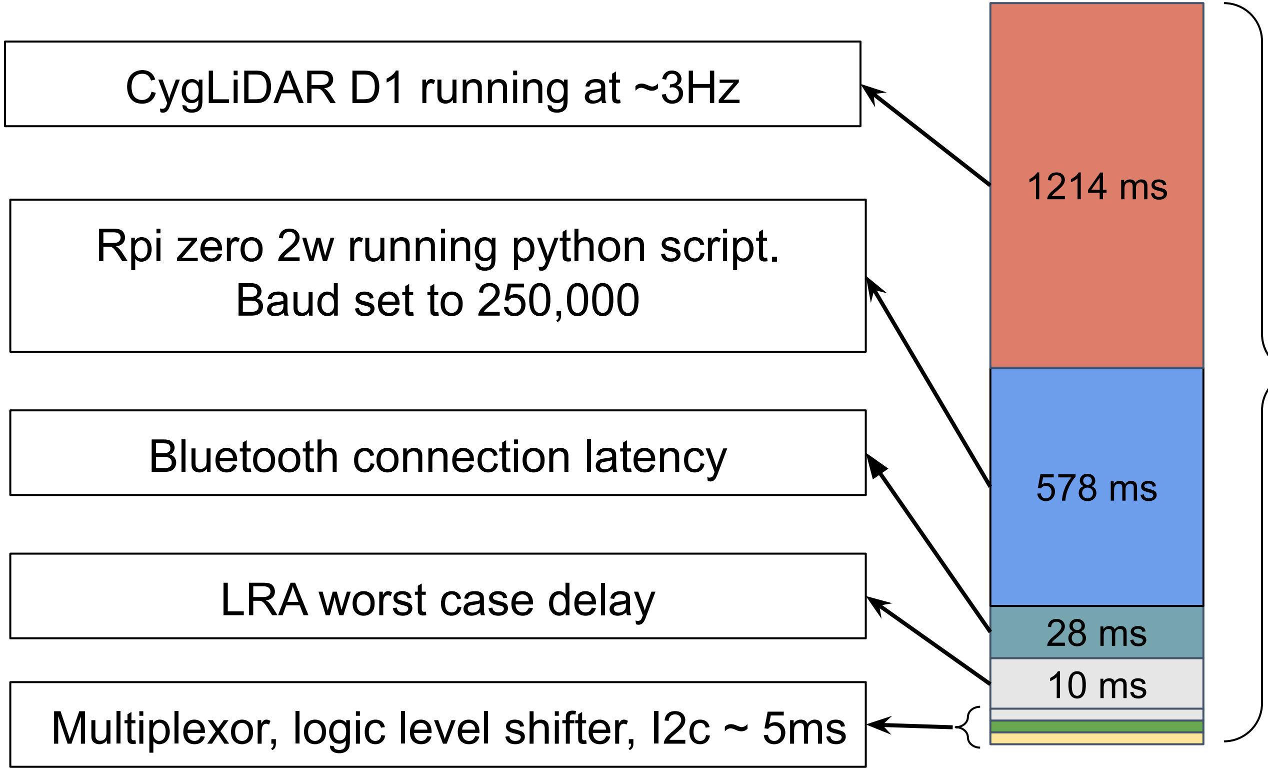

AVG delay = 1.83s
From object presented to vibration

I2c clock at 90.9kHz

Power Consumption - Chest Band

Current measured with all LRA's active and bluetooth ON.

100 mΩ shunt resistor to measure current.

30 Hz LPF applied to Math 2.

Expected Max current	793 mA
Actual current multimeter	210 mA
Actual current oscilloscope	324 mA

Power Consumption - Headgear

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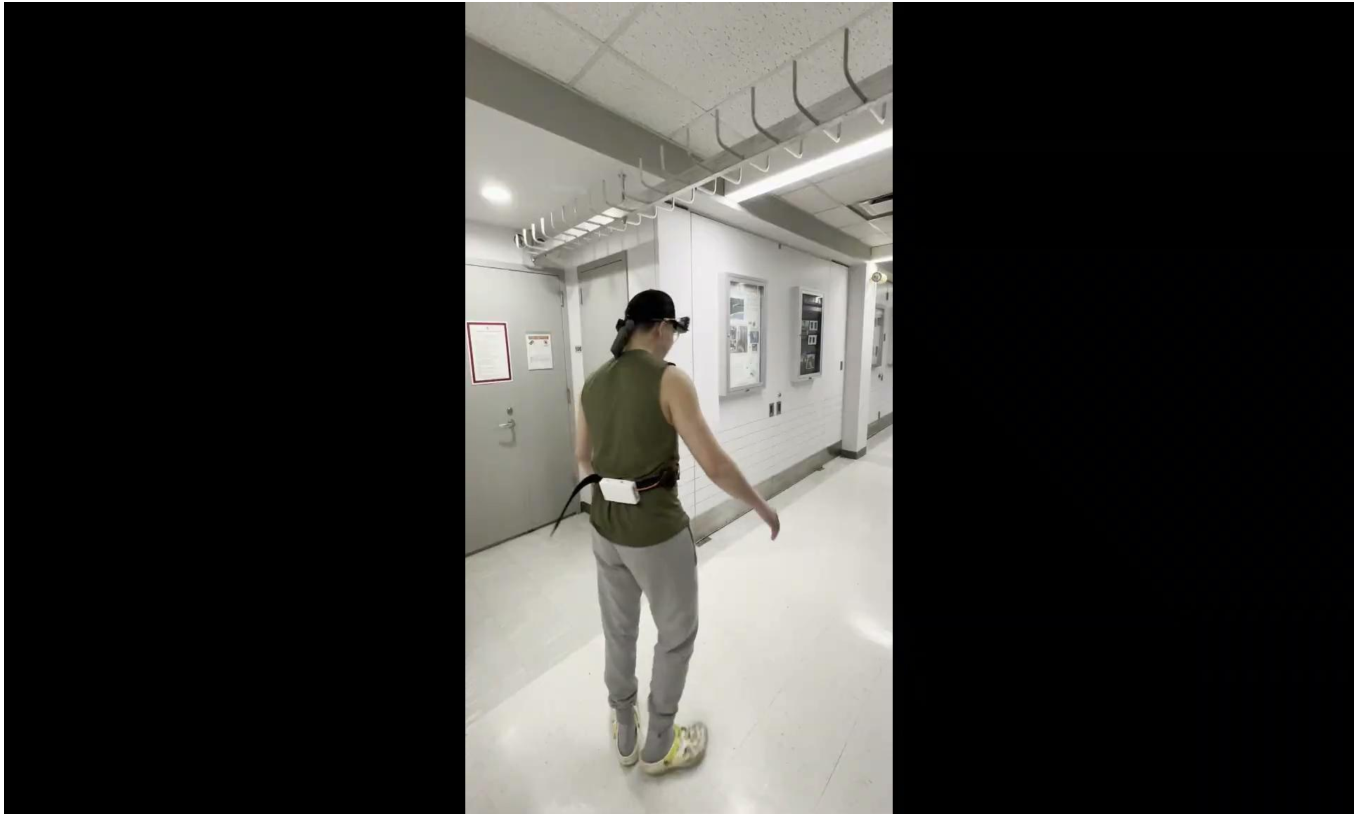
Component	Typical Current (mA)	Voltage(V)	Power(mW)
Rpi Zero 2W w/ BT ON	550	5	3000
CygLiDAR D1	500	5	2500

Total power	5500	mW
Expected Current	1100	mA
Actual Current	662	mA

Current measured with multimeter wired in series between laptop and micro usb cable.

5V Hours of operation	Battery size required(mAh)
3	1950
5	3250
8	5200
10	6500

Demo Video



Demo Video - Latency

FPR Deliverables

- ✅ Complete stand-alone system using battery power
- ✅ Final version of Haptic Vision ready to demonstrate
- ✅ The device will have 5 working LRAs that work based on the data of the LiDAR
- ✅ Decrease the distance threshold with Button 1, on the PCB
- ❌ Adjust the LRA’s intensity via Button 2, on the PCB
- ✅ Improve system latency
  - Processor heatsink, algorithm optimization, increase swapfile size
- ✅ Add security threat model

FPR Full System Testing

Obstacle course to compare Haptic Vision to white cane navigation.

Survey Question 1: How was your experience with the product?

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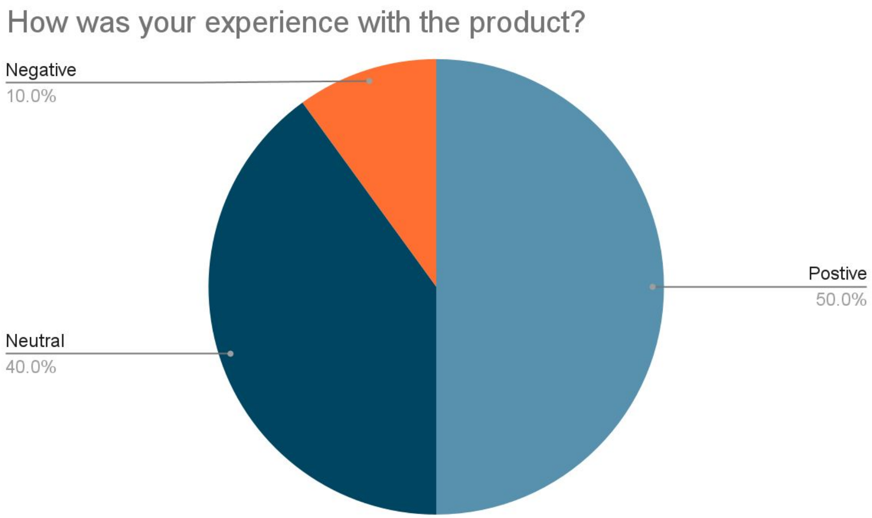
Positive - "My experience with the product has been quite positive. The sensors effectively detected obstacles, and the vibrations on the chest belt were noticeable without being intrusive. Object detection delay is significant and requires slow movements"

Positive - "I found the device very innovative and helpful. The sensors on the hat were lightweight and didn't interfere with my regular activities."

Neutral - "The device was helpful, especially in crowded environments where I need to be more aware of my immediate surroundings. However, it took some time to get used to the vibrations and the initial setup."

Negative - "The product has great potential, but I experienced some discomfort with the headwear after prolonged use. Maybe future versions could have more padding or adjustable features."



Survey Question 2: How easy is it to use our product? And what is your favorite feature of this product and why?

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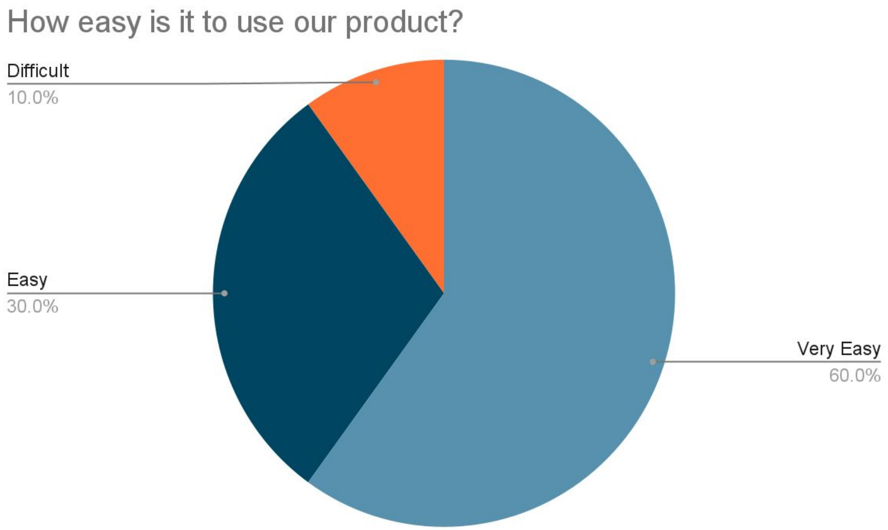

"It was quite easy to get accustomed to the product. The best part is the lightweight design of the headwear. It's comfortable to wear for long periods, which is crucial for daily use."

"Using the product is easy, and it integrates well into my daily routine. The haptic feedback is my favorite feature because it provides a sense of security and enhances my spatial awareness without being invasive."

"The device is user-friendly, but there is a learning curve to get the most out of it. My favorite feature is the haptic feedback on the chest band. It allows me to react quickly to obstacles, which is incredibly valuable."

"I found the product easy to use, thanks to the well-designed interface and clear instructions. The sensors' precision is my favorite feature—they detect even minor obstacles, which greatly helps in tight spaces."

Survey Question 3: Is the haptic feedback recognizable by the user even when they are distracted?

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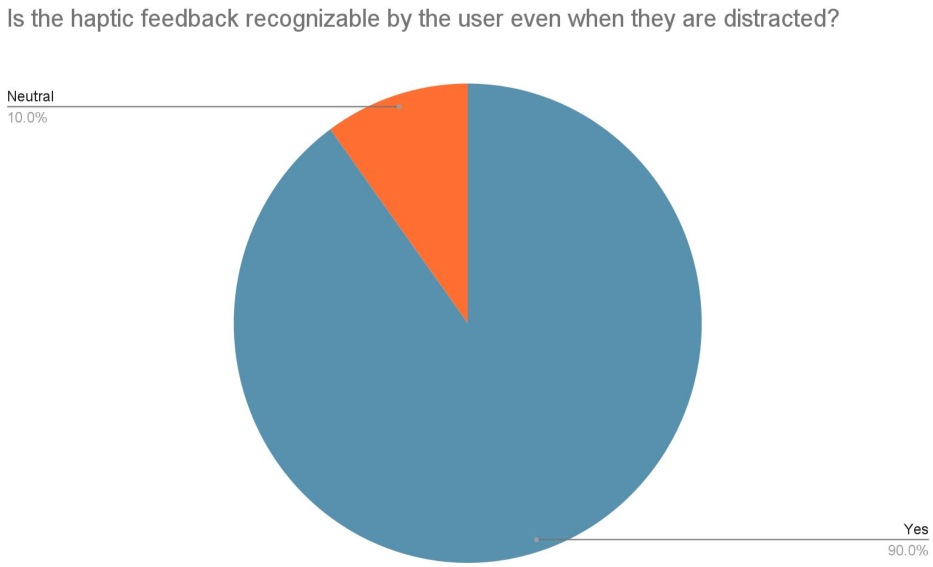
"Yes, the haptic feedback is quite noticeable even when I'm distracted. It has a distinct feel that cuts through whatever else I'm focusing on, alerting me to obstacles efficiently."

"The haptic feedback is strong enough to be felt clearly, even in busy or distracting environments. It serves as an effective reminder of my surroundings without being too intrusive."

"Generally, the feedback is recognizable, but there have been occasions when I was very distracted and almost missed it. Perhaps varying the intensity or pattern based on the level of distraction could help."

"The feedback is mostly noticeable, but its effectiveness can sometimes depend on the type of clothing I'm wearing and the level of external noise."



Product Expenditure

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Order #	Total	$491.78
1	OSHPARK V1, PCB Order	$13.80
2	AMAZON, Raspberry Pi Zero 2w/Micro SD	$38.21
3	Digikey V1	$26.15
4	AMAZON LIDAR	$217.00
5	Digikey V2	$70.76
6	JLC PCB V2	$33.90
7	amazon battery / case zero	$31.53
8	Sparkfun, Raspberry Pi 4 Model B	$60.43

Time Management - Gantt Chart

Tasks	Responsibility	Week 8 [3/25]	Week 9 [4/1]	Week 10 [4/8]	Week 11 [4/15]	FPR Week 12 [4/22]	Demo Week 13 [4/29]	Report Week 14 [5/6]
FPR Preparation	All							
Demo day poster	All							
Demo day prep	All							
SDP report	All							

Questions?

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Prototype Datasheets

1. LRA - VLV101040A
2. Cygbot CygLiDAR D1
3. DRV2605L 2- to 5.2-V Haptic Driver for LRA and ERM with Effect Library (Rev. D)
4. Raspberry Pi Zero 2 W
5. Raspberry Pi 4 Model B
6. N-Channel Logic Level Enhancement Mode Field Effect Transistor BSS138
7. TCA9548A Low-Voltage 8-Channel I2C Switch with Reset
8. 500ASSP1SM6QE Slide Switch

Research Papers

MIT ALVU paper:
https://dspace.mit.edu/bitstream/handle/1721.1/114285/Katzschmann%20et%20al.%20-%202018%20-%20Safe%20Local%20Navigation%20for%20Visually%20Impaired%20Users%20with%20a%20Time-of-Flight%20and%20Haptic%20Feedback%20Device%20-%20Final.pdf

ActiveBelt paper:
https://link.springer.com/chapter/10.1007/978-3-540-30119-6_23