# Haptic Vision

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***Abstract*—In this paper, we introduce Haptic Vision, an innovative contactless device designed to augment obstacle detection capabilities for visually impaired individuals, surpassing the limitations of traditional white canes. Haptic Vision comprises two components: a head-mounted time-of-flight sensor and a chest-worn haptic array. The time-of-flight sensor delivers precision and high-resolution distance measurements. Simultaneously, the chest-mounted haptic band utilizes five linear resonant actuators to provide tactile feedback that conveys the location of obstacles in relation to the user's gaze. This technology promises to empower visually impaired individuals with an advanced and more accurate means of navigating their surroundings, significantly improving their safety and independence.**

## I. INTRODUCTION

Over 295 million individuals have moderate to severe vision impairment, and this number is expected to increase in the coming years. Several factors contribute to these predictions, the aging population, diabetes, and Myopia. As medical advancements continue to extend the average life, eyes remain a point of unstoppable decay for many older adults. Our system, Haptic Vision, aims to help this growing number of vision-impaired individuals by not only increasing their independence but also their safety.

### *A. Significance*

Globally, there are over 43 million people with complete vision impairment, and our team recognizes this opportunity for impactful research and development to improve the lives of this marginalized community. “Projections show that vision loss will increase by 55% or 600 million people over the next 30 years. [1].”

### *B. Context and Survey of Similar Solutions*

Haptic vision draws on many different disciplines and implementation of the other solutions challenged to solve the need for a wider range of reach for the visually impaired. In this section, we dive into these solutions and how our team learns from them.

1. WayBands

WearBands developed by WearWorks is a small wristband navigation device. The system works by linking to a mobile device via Bluetooth, designating a walking path on a GPS navigation system [7]. When the user starts to depart from the set path, the phone app sends commands to the haptic wristband to notify that the user has gone off course via vibrations.

2. Biped

Biped developed by a company Biped.ai is a 900-gram harness-type system that utilizes multiple cameras and a headphone to "see" incoming objects and notify the user. Utilizing an AI from Honda Research Institute as a computing system the camera acted as the input to detect, triangulate, and compute the absolute distance between the user and the object in the 3D plane [3]. The earphones which work via Bluetooth create a 3D surround sound to notify the user of the distance.

3. SmartCane

SmartCane developed by WeWalk works like a regular white cane with extended features. An ultrasound emitter/ receiver is mounted near the handle of the cane to detect objects in its general pointed direction [4]. Upon detection threshold, the cane vibrates and makes a noise to notify the user of an obstacle where then the user may manipulate their body orientation and the cane to successfully navigate around the obstacle.

*C. Societal Impacts*

Our team believes that the implementation of Haptic vision carries significant societal impacts, affecting various constituencies in both positive and, to a lesser extent, negative ways. The primary constituency benefiting from this innovation is the visually impaired community. They experience a positive impact through increased independence, safety, and improved spatial awareness. The extended field of vision allows them to detect obstacles, identify objects, and navigate their surroundings more effectively. Furthermore, caregivers, family members, and friends of visually impaired individuals also experience positive effects, as they witness the enhanced quality of life and increased autonomy of their loved ones.

However, there are multiple potential negative impacts we must address. One such impact is related to privacy and data security as LiDAR technology captures detailed information about the environment. Ensuring that this data is used responsibly and safeguarded is essential. Furthermore, there are issues regarding the degree of societal resistance or apprehension toward the adoption of such technology, which stems from concerns about cost, accessibility, and the perception that it could replace traditional methods of mobility training or the use of guide dogs. Our team carefully addresses these potential issues, offering confidentiality, affordability, accessibility, and clear communication to minimize any negative consequences.

*D. Goals, Specifications, and Testing Plan*

Our system's goal is to correctly detect distance from an object (from at least 6 feet), last for a day's use, and be protected from external damage. To test the device's functionality, we enlisted 10 randomly selected volunteers, 1 individual who is visually impaired and 9 who are not, to test our system and to give us their reviews in the form of a survey. We surveyed 10 individuals from a diverse pool of age and gender. Each volunteer was assigned to put on the system and engage with it in a controlled environment, performing a series of tasks designed to test the key features and usability of the device. To test if the device provides feedback to the individual, our team created an obstacle course with various objects, ranging from 0 to 6 feet. Our team tested the accuracy of the system's object detection by measuring the distances of small objects, one object in the center then one each 30 degrees to the left and right of the system. Then we compared the system's output to the actual distance and direction of the object. The data of participant feedback, observations of the individuals, and device performance was analyzed to identify if the device functions as intended or has issues. To test the durability of the system, we assessed its protection against external damage to ensure it meets the standards. Our goal was for the system to be protected against a solid object greater than 50mm, such as a hand. We implemented this durability requirement with a drop test, or dropping our system from a certain height. We also implemented an ingress protection test called the dripping water test, which made sure that the system is protected against vertically falling drops of water. This test was particularly important as this test plays a crucial role in producing a durable and safe device. This is to ensure that the device should experience no harmful effects from dripping water. The test was executed for about 10 minutes with water dropping equivalent to 1 mm of rainfall per minute.

| **System Specification** | **Test Plan** |
|---|---|
| System will be able to detect obstacles from <=6ft. | Get distance to print on terminal, manually measure distance. |
| System will give different haptic feedback for different ranges:<br>Haptic Single click: 6' ≥ range > 4'<br>Haptic Double click: 4' ≥ range > 2'<br>Haptic Triple click: 2' ≥ range > 0' | Observe LRA clicks at the three different range regions. |
| 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. |
| 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. |

*Table 1: Specifications and Testing Plan*

II. DESIGN

This section describes the system design including design alternatives, design justifications, and hardware and software block diagrams.

*A. Overview*

Our design consists of two major parts: the hat-mounted obstacle detection sensor, the CygLiDAR, and the chest-mounted haptic array. The connection between the head and chest elements is made wirelessly via Bluetooth communication.

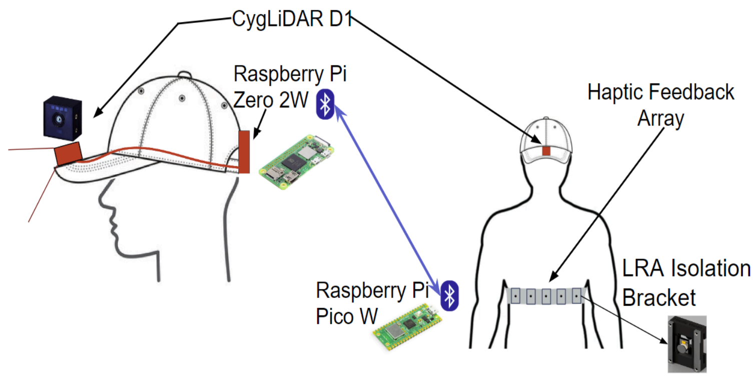



*Figure 1: Design overview with key elements.*

*B. Hardware Block Diagram*

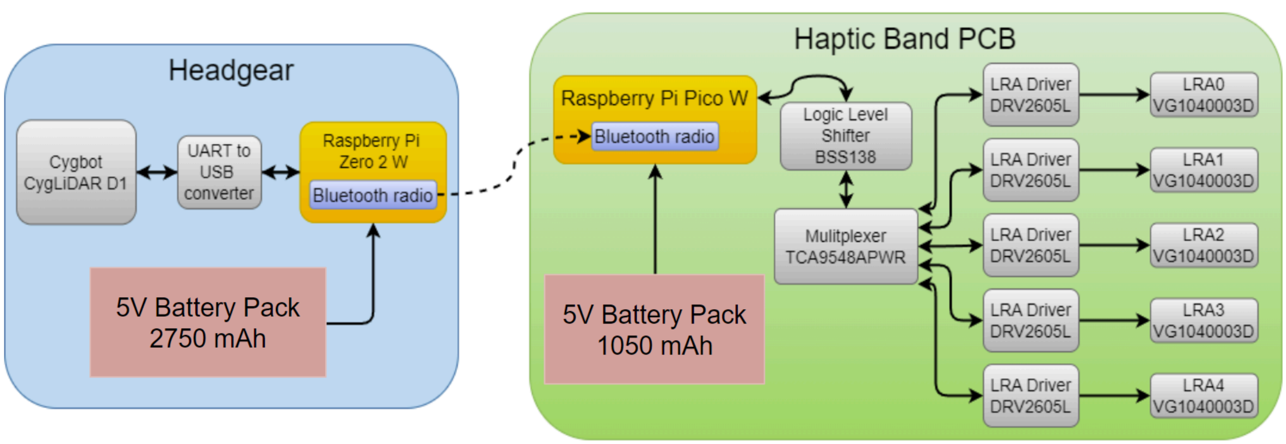
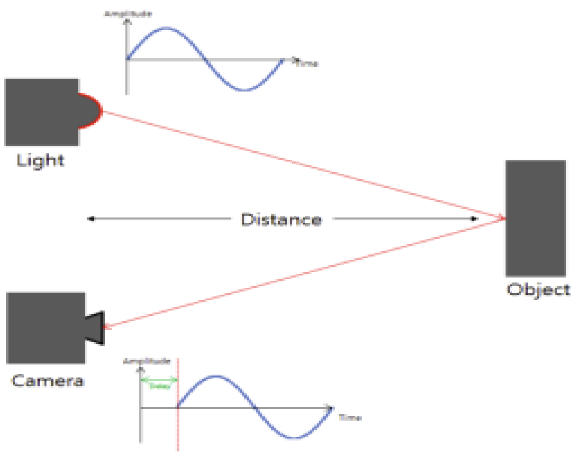



*Figure 2: Hardware block diagram detailing major components and location of hardware.*

*C. Lidar Time of Flight sensor block*

To detect obstacles our team decided to use a LIDAR sensor that has high accuracy and a large field of view. The Cygbot CygLiDAR D1 emits infrared light beams that bounce off objects in the beam path. The reflected beams then hit a camera, which is built into the component. This lidar uses a different distance measuring technique than many other single-point lidar systems which use a simple time of flight calculation. The CygLiDAR D1 uses a phase shift method to detect distance, which increases data collection but also reduces the range of the sensor.




$$Time\ of\ Flight = \frac{Phase\ Shift}{(2\pi * Modulation\ Frequnecy)}$$

*Figure 4: Cylinder D1 Datasheets phase shift measurement diagram and phase shift method equation.*

*D. Haptic feedback array block*

Mounting the haptic array across the user's chest offers a substantial area for sensing tactile vibrations, which is advantageous for navigation. To ensure the clarity of this feedback, it's important to position the haptic elements as far apart as possible, preventing vibrations from becoming indistinct and enabling users to discern the direction and location of obstacles more effectively. Our decision to use vibrations as the primary means of communicating obstacles stems from several considerations. Firstly, tactile feedback is localized to the wearer and discreet, making it a non-intrusive way to convey information. In contrast, audio feedback, unless used with headphones, can be disruptive and may interfere with other senses, such as hearing. We also ruled out audio feedback because it would limit accessibility for the approximately 160 million deafblind individuals worldwide [5]. Furthermore, research such as the aforementioned MIT paper has shown that vision-impaired individuals typically prefer not to rely on audio as a navigation system, “Feedback from the blind community demonstrates a dislike for audible feedback from the device, due to a preference to use their hearing for freely observing the environment [6].” The blind community often expresses a preference for using their hearing to freely observe their environment. Additionally, while exploring different haptic options, we considered electric sensation, like transcutaneous electrical nerve stimulation (TENS) muscle stimulation therapy. However, we ultimately decided against this approach due to safety concerns related to connecting electrodes to a human. This choice ensures the safety and comfort of our users.

*E. Software Block Diagram*

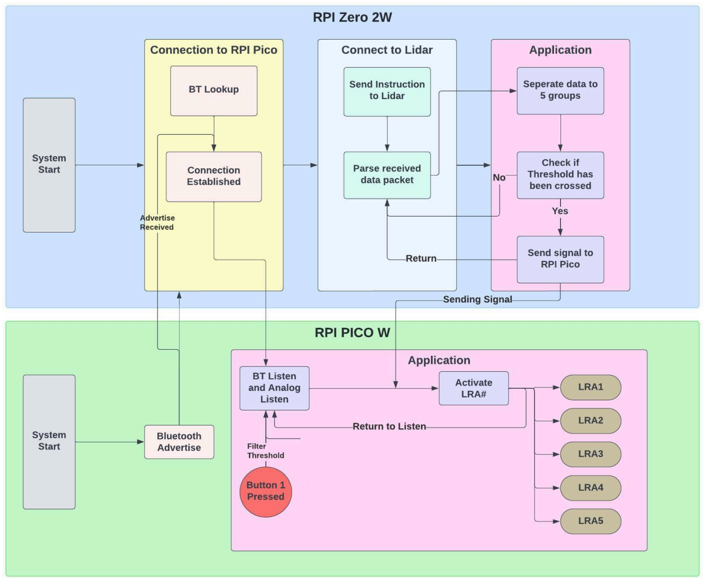



*Figure 5: System On Chip Software Block and Flowchart.*

*F. Software Design*

Our software design utilized the Raspberry Pi Zero 2W and Raspberry Pi Pico W. Both RPIs were scripted to run their predefined programs upon startup. Upon startup, the Raspberry Pi Zero 2W is initialized and attempts to connect to the RPI Pico W. Once the connection is established, RPI Zero 2W sends a command to activate 3D mode on the LiDAR and begin receiving data. The RPI Zero 2W then parses the data stream to populate a double array, forming a 2d matrix with a distance datapoint. The data points were then partitioned into 5 different angle groups based on their horizontal-angular position in the matrix. We then consolidated the angle group's output distance by finding a grouped data point that has the closest measured distance. The grouping of data points was done to catch false detection from a single data point. Upon consolidation, we are given an array with five different values which represent the distance of an object at each angle group. If the absolute distance of a certain angle group crosses a certain threshold, RPI Zero 2W sends a message to RPI Pico W via Bluetooth. The content of the send message is a specific int value which represents which angle group the threshold was triggered and which of the 4 defined threshold was crossed. Each threshold was determined by the proximity of the object to the system. Once the RPI Zero 2W sends the instruction to the PCB system via Bluetooth, the RPI Pico mounted on the PCB sends instruction signals to the LRA driver which then decides which LRA would respond and in what pattern. The PCB system also has a feature to change the distance at which the LRA is triggered. The program waits for a button to be pressed on the PCB. If the button is pressed, the threshold in which the LRAs would react is changed. The program continued to run and update the data until termination.

### *G. Security Design*

Our Haptic Vision system incorporates three crucial security features to safeguard confidentiality, authenticity, and ensure disaster recovery. These measures are imperative due to the utilization of Bluetooth communication between our two systems, exposing vulnerabilities such as packet sniffing, replay attacks, and unauthorized connections. We also found that most errors we encountered in the development of our systems were rooted in our use of Bluetooth. To address these concerns, our system employs OTP encryption, guaranteeing confidentiality in the communication between RPI Zero and RPI PICO. Additionally, we implement a connection validation mechanism based on MAC addresses, ensuring authenticity by permitting only designated systems to connect. Moreover, our disaster recovery strategy involves the implementation of a robust error-handling mechanism, utilizing try-catch methods. In the event of errors, the system gracefully closes all Bluetooth connections and ongoing processes before initiating a system restart, seamlessly re-establishing the connection between both systems. This comprehensive approach fortifies our system against potential security breaches, ensuring seamless operation and data integrity.

## III. THE PROTOTYPE–CDR

### *A. Prototype Overview*

Our prototype consisted of implementing the main features of our system, that is obstacle sensing with a simplified signal processing pipeline and the tactile feedback driver circuit. The prototype proved that we receive adequately accurate sensor information for object detection as well as show that all components can work together, including controllers, sensors, and haptic drivers. The pipeline for our prototype is as follows: RPI Zero and RPI Pico establish a connection with each other. Distance information is gathered by the LIDAR and fed via UART to our RPI Zero, which then processes the information, analyzing it with pre-defined parameters. If the processed data triggers a threshold in the defined parameters, the RPI Zero sends a message to RPI Pico which then sends commands to the PCB through an I2C bus, which activates vibration patterns to a specific LRA depending on which message was received from the RPI Zero.

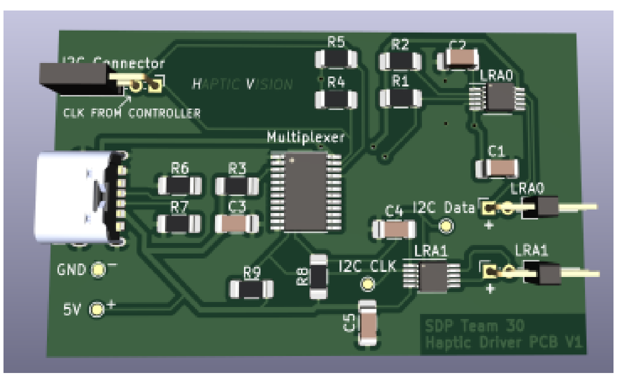
*B. List of Hardware and Software*

The major hardware components consist of a laptop which was used to run the programs for the hardware. For object sensing, we used the Cygbot CygLiDAR D1 LIDAR. These two components communicate over UART. For our haptic array prototype, we used the strongest linear resonant actuator that Vybronics manufactures, the 10mm VLV101040A. This LRA is popular in the Galaxy Z Flip 3 and Samsung Galaxy S21 smartphones. For RPI Zero 2W, our team used Python language to script the system and used Pypy interpreter to execute the program. For RPI Pico W, we used micropython language to script the system and micropython interpreter to execute the program.

*C. Custom Hardware*

C.1 PCB

The custom prototype printed circuit board is powered with a USB type-c connector. incoming data over I2C is run through a Texas Instruments 8-channel multiplexer TCA9548APWR. The multiplexer is required for our final build when we have more than one LRA driver running on the same I2C bus, as they all have the same fixed register. The LRA drivers are also from Texas Instruments, the Ti DRV2605LDGSR Haptic driver. The board has multiple SMD 1206 resistors and capacitors.



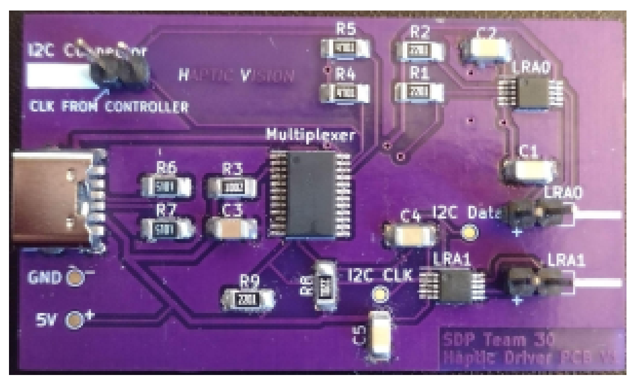




*Figure 6: Left, prototype PCB model of haptic driver. Right is the built prototype PCB with solder component*s.

C.2 Isolation bracket

Another critical piece of prototype hardware that was made for CDR was the LRA isolation bracket. The bracket solves three main problems:

1. Isolation of vibrations
2. LRA constant tension

3. LRA chest band attachment

The isolation bracket enhances user experience by employing a slender rubber element to pre-tense the Linear Resonant Actuator (LRA) against the user's skin, effectively isolating vibrations to a specific point. This design optimally directs directional sensing among the five distinct vibration motors positioned across the chest. Without this isolation, the risk of vibrations spreading along the entire band arises, potentially causing a loss of clarity in perceiving object direction. This challenge is particularly pronounced for users with smaller frames, as the LRAs become more concentrated on the chest band, intensifying the potential for blurred directional feedback. The design was adapted in part from Katzschmann's isolation bracket [6].

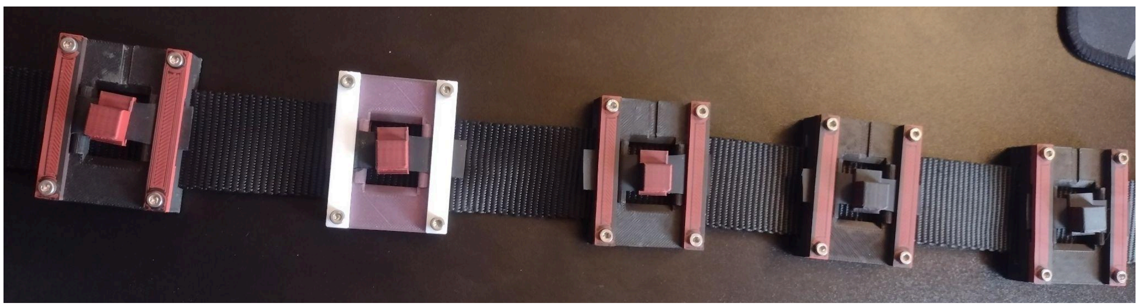


*Figure 7: 5 isolation brackets mounted on a belt*

*D. Prototype Algorithm*

The algorithm is designed for object detection using Lidar technology. It starts by initializing the Lidar in Mode 2, which activates it in 3D scanning mode. In this mode, the Lidar scans and after the scan generates 9600 data points across an angular range from -60 to 60 degrees. To enhance accuracy and reduce false positives in detecting an object, these 9600 data points are segmented into 5 groups. This is achieved by finding average 3 min values among the data points within each group, resulting in 5 consolidated data points. If a segment does not detect an object it assigns a distance value of zero to that segment. Additionally, if an object is detected but is beyond the set threshold of 1.8 meters (approximately 6 feet), the distance value for that segment is once again set to zero. Finally, the algorithm outputs the distance of objects, but only for those that are within the 1.8-meter threshold. The algorithm then uses the processed data to produce an integer between 0 and 19 that reflects the object's distance and angle group. This integer is used to inform which LRA to activate along with the number of pulses for it. Each set of 4 numbers within the 0-19 range is mapped to a specific LRA and pulse count.

For secure communication between the two RPis, the integer is first converted to a byte value. This byte value then undergoes an encryption process using OTP-XOR encryption, resulting in a string that contains the encrypted data. Once encrypted the string is then sent from the Raspberry Pi Zero W to the Raspberry Pi Pico W via Bluetooth.

Once the data is received by the RPi Pico, it converts the string back to a byte value which is then decrypted by applying the XOR operation again. Using this decrypted integer, the Raspberry Pi Pico W identifies the correct LRA to be activated along with the number of pulses for it. This process is done using division and modulus. By dividing the integer by 4 it determines which LRA and by performing a modulus of 4 it determines how many pulses.

### *E. Prototype Functionality*

The PCB prototype we used for CDR took I2C inputs from an Arduino Uno, for ease of programming. The prototype was able to talk to each of the two LRA drivers via the multiplexer which is centrally located in the board as seen in Figure 6.

### *F. Prototype Performance*

For our prototype, our team was able to showcase successful communication of obstacle information through haptic feedback. Our team gained the test results by demonstrating accurate haptic patterns for different obstacle distances and directions. Our team also presented data comparing actual obstacle distances with sensor readings. The data demonstrated the accuracy and reliability of the distance measurement system. The prototype also provided test results showing the system's ability to consistently detect obstacles from a minimum distance of 6 feet. However, the main system (RPI Zero 2W) was not capable of effectively handling the data stream received from the LiDAR in real-time. Therefore, there was a 1-2 second delay between the detection and the computer recognizing the detection. The system utilizes two batteries in total, one for the headgear and the haptic band. The haptic band can operate for 12.5 hours of continuous operation. The headgear can last for 7.6 hours of continuous operation. Since both parts are required for system operation, the real operation time is limited by the headgear at 7.6 hours. We could have made the battery life of the haptic band match the headgear but we used battery packs that we had on hand, to avoid going over our budget.

## IV. FPR Final Design

Our final design consisted of a fully functional standalone system. At its core is a LiDar sensor designed to attach to any brimmed hat which is connected to a Raspberry Pi Zero 2W for data processing. This is complemented by a chest band equipped with 5 LRAs, controlled by a Raspberry Pi Pico W. The lidar sends data to the RPi Zero 2W which is then processed. Once processed, the RPi Zero 2W sends the processed data via Bluetooth to the RPi Pico W. Finally the RPi Pico W decides which corresponding LRA to activate. Along with this, we added three security features to our design. Our first security feature utilizes MAC addresses for authentication between the two RPIs. Our second feature utilizes a simple OTP encryption/decryption algorithm. Our third feature implemented a try-catch method to intercept and gracefully handle all errors, ensuring disaster recovery.

### *A. CDR design Overview*

Building off what we learned from our initial prototype from MDR, we expanded our design to incorporate more LRAs and wirelessly connect between the head processor and the haptic chest band. We choose to use a Raspberry Pi Pico W as it has radio and power conversion and easily configurable GPIO pins at a price that is much more affordable and is stocked at M5. Alternatively, we could have bought an ASIC for Bluetooth to i2c conversion, for around 5 USD for Nordic semiconductors.

### *B. Custom Hardware*

The haptic chest band PCB has been expanded to allow for up to 5 LRAs to be driven as well as a Bluetooth connection with the main processor on the head with the RPi Pico W. The PCB also has a main disconnect switch and a small button to allow for user toggleable distance thresholds. This version of the PCB has all the features of the old prototype but now includes protection diodes and logic level shifters to convert 3.3V logic up to 5V logic.

### *C. Pypy vs CPython Interpreter*

In our previous MDR prototype, we initially employed the CPython interpreter in our RPI Zero 2W system due to its widespread adoption and compatibility. However, we encountered significant latency issues during the parsing of LiDAR data inherent to Python's standard interpreter, impacting the responsiveness of our system. Recognizing the critical need to address these performance bottlenecks, we explored alternative solutions to enhance speed and reduce latency. The solution we came up with was Pypy, a JIT-compiled Python interpreter renowned for its ability to dramatically improve execution speed and optimize performance for compute-intensive tasks. By leveraging Pypy's JIT compilation capabilities, we successfully mitigated the latency issues plaguing our previous design. The enhanced speed and responsiveness afforded by Pypy not only bolstered the overall performance of our system but also significantly improved the user experience.

In light of these compelling advantages, we transitioned to the Pypy interpreter for our final design iteration, prioritizing speed and efficiency to meet the stringent requirements of our standalone system. This strategic decision yielded tangible benefits, ensuring that our system delivers optimal performance and responsiveness, thereby enhancing its utility and effectiveness in real-world applications.

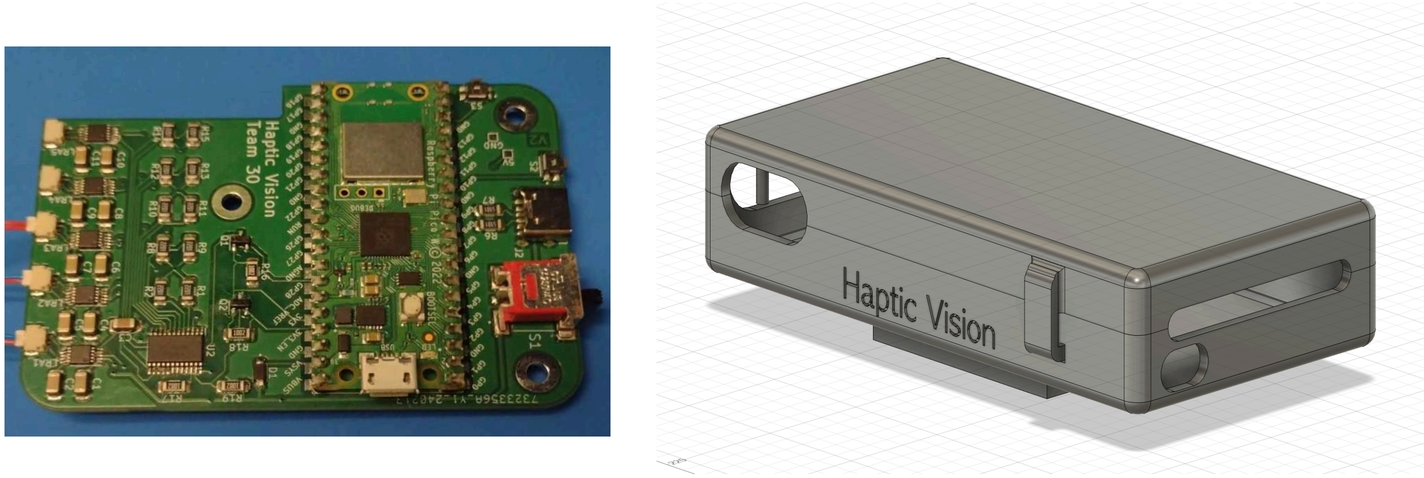



*Figure 7: Left: Final Haptic Vision PCB. Right: 3D printed case design for PCB.*

## V. CONCLUSION

Currently, our team has finalized the final design for the device and built the final prototype. Our device consists of 5 LRA modules and the implementation of the main system where obstacles are sensed with a simplified signal processing pipeline as well as the tactile feedback driver circuit implemented connecting between the two systems. During our evaluation, an issue pertaining to security threats to our system was addressed, specifically regarding replay attacks. We have addressed these threats by adding a security threat model and a counter-security measure to our system, in the FPR deliverables.

## REFERENCES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APPENDIX

*A. Design Alternatives*

The main limiting factor for our system is cost. The CygLiDAR is a hobbyist-grade solid-state sensor. There are a multitude of more precise sensors we could have used. Terabee, and Leishenlidar both make higher-grade sensors that have more range in 3D operation. For example, if we used the LS MS-CH32, we could measure distance at 200m away, but the unit cost $3,333.33 and is well out of our allowed budget.

Another limiting factor discovered is the processing power of the RPi Zero 2W. With a larger budget, you could use a Radxa Zero 3W, which has about three times the processing power, all while keeping the same small form factor which is important for head-mounted devices.

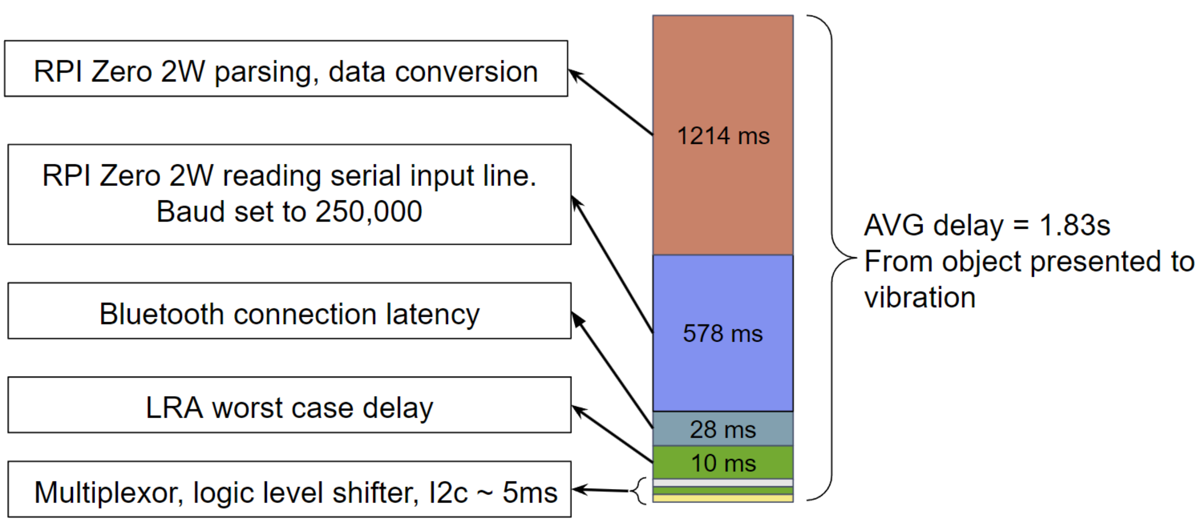
*B. Technical Standards*

In regards to standardized hardware and software, we used IEEE 802.15 (Bluetooth) to connect and draw information from the internet containing our references.

*C. Testing Methods*

To measure the power consumption of our system we used a benchtop oscilloscope with a 0.1ohm shunt resistor. We also utilized a 30Hz low pass filter to remove 60Hz noise from our measurements. This allowed us to find the time average current coming out of the 5V battery packs.

To measure the latency of our system we used a combination of software timekeeping and real-world measurements to record the sense-to-feedback delay. The sense-to-feedback delay is the time it takes for the lidar to detect an obstacle and for the haptic LRAs to actuate.



*D. Project Expenditures*

| 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 |

**E. Project Management**

Our team was divided into mainly two parts. We had the hardware team and the software team. Ryan and Jordan were part of the hardware team. Ryan mainly dealt with the PCB while Jordan was in charge of 3D printing. Alvin was responsible for the algorithm for the device whereas Jeffrey was responsible for the Bluetooth communication. The team worked well as we divided the project and were able to work in parallel with each other. We communicated through a group chat where we updated each other on our progress on specific parts. Through this, we were able to help each other out because if one person needed help another person could join and tackle the problem with them.

**F. Beyond the Classroom**

Ryan - Prior to senior design, I was completely unfamiliar with PCB design and workflow. The creation of Haptic Vision necessitated a straightforward circuit board utilizing SMD components, and I acquired all the necessary knowledge through Digikey's KiCAD tutorial videos. This experience solidified the notion that formal education isn't always a prerequisite for acquiring new skills and constructing a functional device. Additionally, a significant aspect of the project involved extensive research into various components of the circuit board, including thorough comparisons of datasheets for similar parts.

Alvin - My biggest hurdle diving into this project was working with latency of the device and modules that I was completely unfamiliar with. Navigating the intricacies of these components required a combination of hands-on experimentation and diligent research. YouTube tutorials on PCB design and manuals for each specific module proved invaluable resources, guiding me through the complexities of hardware integration and troubleshooting. Throughout the development process, I encountered numerous challenges and setbacks, from optimizing system performance with tools like ROS1 and Pypy to configuring software for compatibility with our hardware architecture.

In overcoming these obstacles, I honed essential skills in problem-solving, adaptability, and resourcefulness. Learning to effectively utilize GitHub for version control and collaboration was particularly instrumental in streamlining our workflow and ensuring project cohesion. Additionally, delving into research papers expanded my understanding of relevant technologies and methodologies, giving me the skill sets to hone my knowledge base and implement strategic decision-making.
Looking ahead, I recognize the profound impact of this project on my professional growth and development. The hands-on experience gained through navigating the complexities of applying software integration on a PCB design has equipped me with invaluable skills applicable across various industries. This SDP journey has been instrumental in shaping my technical proficiency, fostering a deeper appreciation for interdisciplinary collaboration, and preparing me for future challenges in my professional career.

Jordan- My biggest hurdle was designing in Fusion360, as I had no prior experience with it before the SDP. I acquired most of my knowledge through 3D printing tutorial videos on YouTube and resources on Google. When creating the 3D printed case for the PCB, I had to undergo multiple stages of development. Some designs were too small or fragile, leading to a lot of trial and error. Each iteration brought new ideas for improving the functionality of the case. After three different versions, this process significantly enhanced my adaptability and problem-solving skills.

Jeffrey - My biggest hurdle was learning how to work with Bluetooth. Prior to SDP, I had never worked with Bluetooth or the libraries within Python that dealt with Bluetooth. I was in charge of the majority of the Bluetooth aspects of our project so it proved difficult to do without prior knowledge. I needed to develop problem-solving skills along with self-learning. I had to teach myself how to work with Bluetooth. Problem-solving was very important when it came to debugging problems. Anytime something didn't work as expected I had to figure out what was wrong and how to fix it. That meant testing specific parts of the project, whether it be the hardware or software and finding a fix for it.  YouTube and Google have been very helpful.

Anytime I had a question or a problem I would go to Google and Youtube. Google and YouTube have been very important resources in helping me to teach myself everything I needed to learn for this project.

With the skills I've learned on this project, it would be very beneficial to my life as a professional. The ability to self-teach yourself something and apply it will be very important to any job I will have in the future. If I had a problem it's better to learn about it myself before asking for help so it would make working in a team easier. I've also become more knowledgeable about software which is always a huge positive when it comes to working in the software engineering industry.

**G. System Specification - Detection distance**

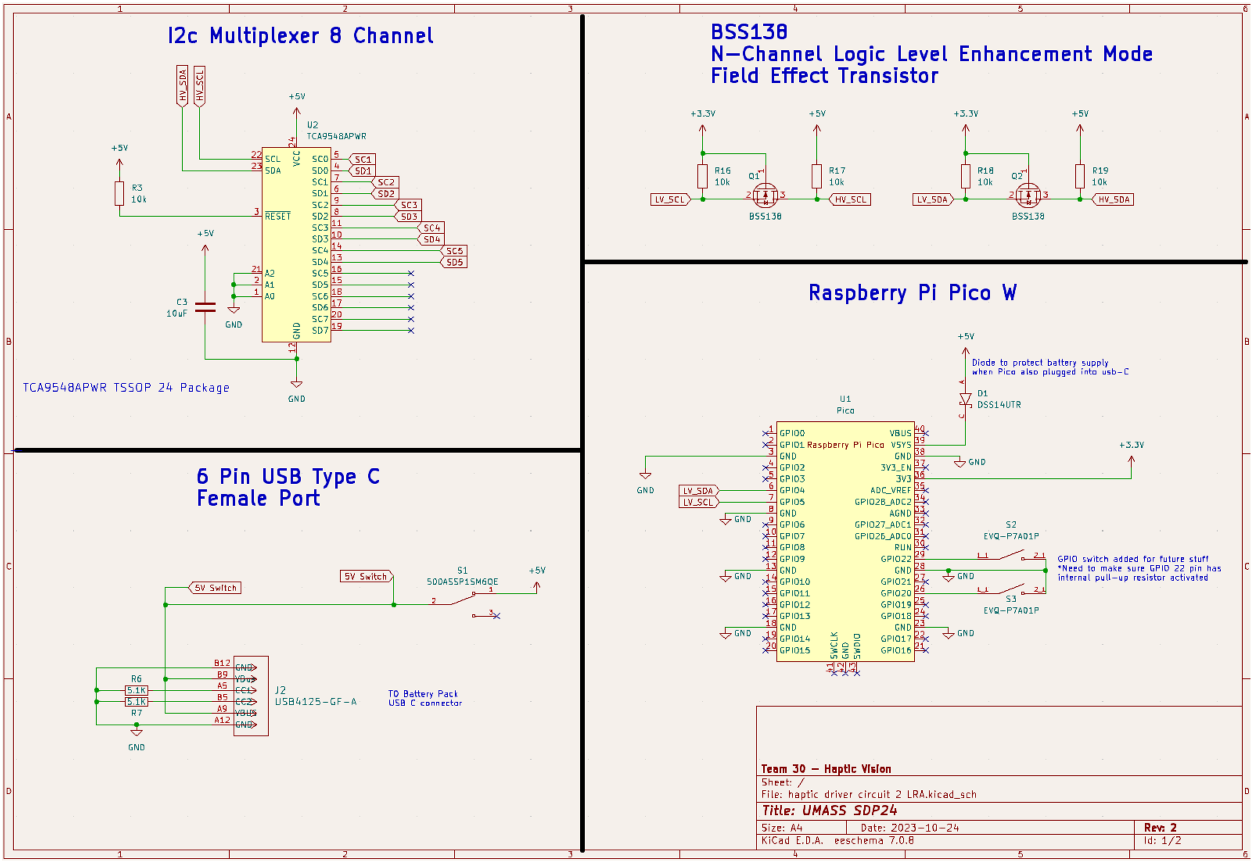
In the pursuit of optimal obstacle detection, our system empirically determines and leverages the maximal operable distance attainable with contemporary hobbyist-grade hardware. Since the max distance threshold is set by the type/quality of the LiDAR selected, which is also reasonable in our budget, we have set the object detection distance to the max range of the LiDAR.

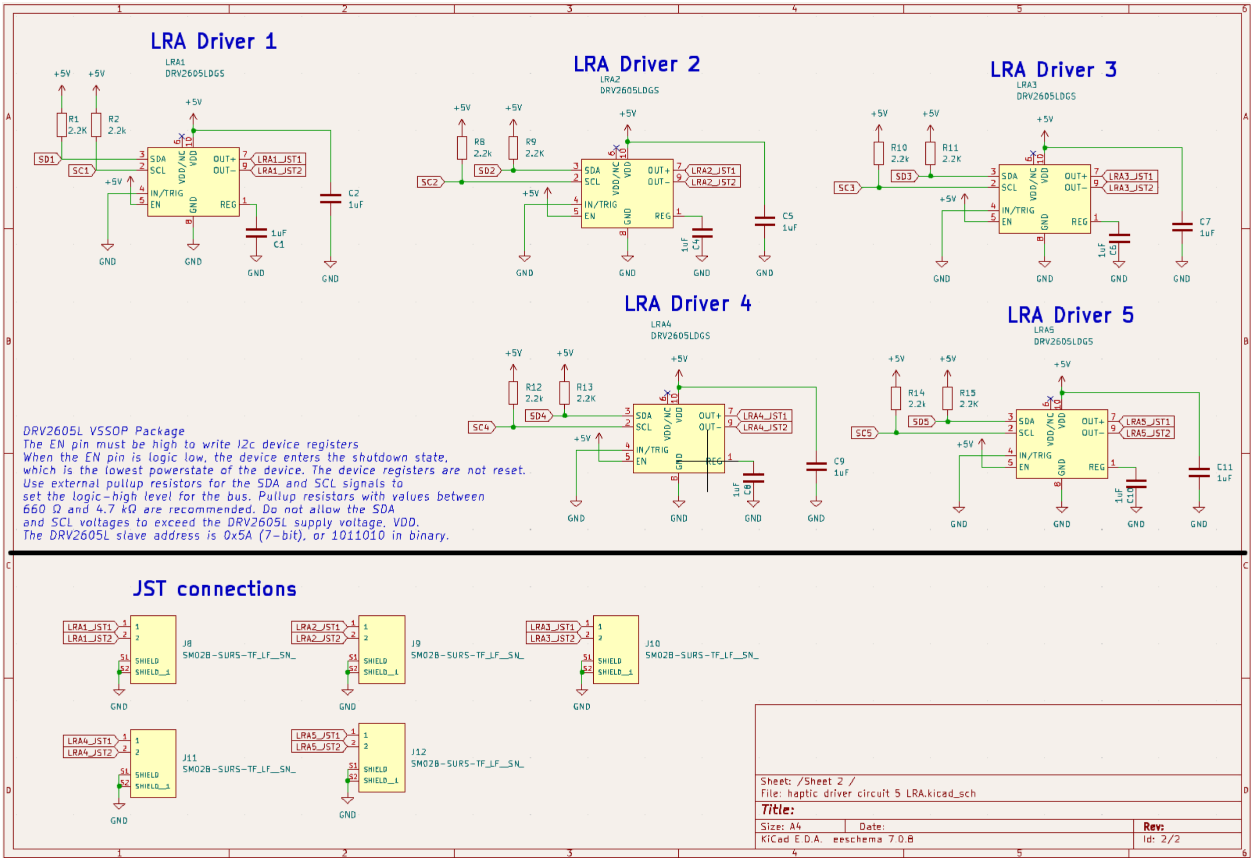
**H. Lessons Learned and Message to Future SDP Teams**

While our design is functional, the latency issue significantly impacts the practicality of Haptic Vision. Our primary takeaway is the importance of simplicity. Initially, we entertained too many additional features, but fortunately, we were dissuaded during the initial design review. It's common for SDP teams to aim high, but prioritizing a basic functional system initially, and then gradually incorporating additional features post-verification, proves more effective. Another lesson was underestimating the processing power needed for a 3D lidar sensor. Although our chosen processor can handle the calculations, the runtime is lengthy, as detailed in section 4.C. In a user-interpreted system relying on haptic feedback, minimizing latency is crucial, ensuring users can make decisions only after computation completes. Lastly, we learned the value of early adaptability. If a design element isn't working, it's better to pivot sooner rather than later.

A piece of advice for teams considering a similar haptic navigation system for their SDP project: avoid Raspberry Pi and Python. While Raspberry Pi is versatile, it lacks the speed and efficiency required for our purposes. Similarly, although Python is user-friendly, it struggles to keep up with the continuous data streams with 3 million baud rate demanded by our LiDAR. In fact, Python interpreter's processing speed can be up to 100-1000 times slower than a C interpreter doing the same task depending on the complexity of the code. We instead suggest a more powerful single-chip computer such as Radxa and a low-level computer language such as C.

**I. Final PCB Schematics**


I2c Multiplexer 8 Channel
TCA9548APWR TSSOP 24 Package
BSS138
N-Channel Logic Level Enhancement Mode
Field Effect Transistor
Raspberry Pi Pico W
Diode to protect battery supply
when Pico also plugged into usb-C
GPIO switch added for future stuff
*Need to make sure GPIO 22 pin has
internal pull-up resistor activated
6 Pin USB Type C
Female Port
TO Battery Pack
USB C connector
Team 30 – Haptic Vision
File: haptic driver circuit 2 LRA.kicad_sch
Title: UMASS SDP24
Size: A4
Date: 2023-10-24
Rev: 2
KiCad E.D.A. eeschema 7.0.8
Id: 1/2


LRA Driver 1
LRA1
DRV2605LDGS
LRA Driver 2
LRA2
DRV2605LDGS
LRA Driver 3
LRA3
DRV2605LDGS
LRA Driver 4
LRA4
DRV2605LDGS
LRA Driver 5
LRA5
DRV2605LDGS
DRV2605L VSSOP Package
The EN pin must be high to write I2c device registers
When the EN pin is logic low, the device enters the shutdown state,
which is the lowest powerstate of the device. The device registers are not reset.
Use external pullup resistors for the SDA and SCL signals to
set the logic-high level for the bus. Pullup resistors with values between
660 Ω and 4.7 kΩ are recommended. Do not allow the SDA
and SCL voltages to exceed the DRV2605L supply voltage, VDD.
The DRV2605L slave address is 0x5A (7-bit), or 1011010 in binary.
JST connections
J8
J9
J10
J11
J12
SM02B-SURS-TF_LF__SN_
Sheet: /Sheet 2 /
File: haptic driver circuit 5 LRA.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. eeschema 7.0.8
Id: 2/2