3 Design

3.1 DESIGN CONTENT

The product intends to create an interface by which users with visual impairment can interact with to assist in their everyday activities. The product can be simplified into three main contents that work synchronously to provide a unified system.

The first content section is the stereoscopic cameras, which facilitate a means to view the environment in a natural way. By capturing images and triangulating depth, the tangent cameras act as simulated eyes that pass data that can be transmitted to the next content section, the haptic feedback array. The array of motors located throughout the body of the user provides different frequencies of vibration to relay depth information. Furthermore, different patterns of pulses can be used to signify different landmarks or any other vital information besides depth. The last content section is the bridge that provides the computing between the two previous content sections. Facilitated by a handheld general-purpose computer, such as a Raspberry Pi or the likes, all data from the cameras will be processed and translated into a series of frequencies for the motor array. Further content includes power management and testing systems that will be covered in detail in the following sections.

3.2 DESIGN COMPLEXITY

1. Stereoscopic Camera
   (a) Principles of computer vision and depth sensing.
   (b) Stereoscopic vision.
2. Raspberry Pi
   (a) Interfacing camera + motors with Raspberry Pi.
   (b) Includes knowledge of hardware communication and software integration.
3. 4x4 Grid Generation
   (a) Understanding principles of spatial mathematics for creating/mapping a grid.
4. Haptic Motor Array
   (a) General engineering principles come into play for the design and construction of 4x4 array of haptic motors.
   (b) Electrical engineering knowledge required to connect the array to Raspberry Pi.
5. Power Management
   (a) Efficiently managing power supply for the Raspberry Pi and haptic motor array. Electrical engineering and energy optimization principles.
6. Testing and Calibration

   (a) Requires knowledge of testing and debugging.

7. Safety

   (a) Incorporates safety engineering and risk assessment to ensure the system is safe for users and operates reliably.

3.3 MODERN ENGINEERING TOOLS

1. **Intel RealSense D435i** - Primary input device, responsible for capturing depth information to be transmitted.

2. **Raspberry Pi** - Serves as the central processing unit. Receives data from the camera, processes it, and controls the haptic motors.

3. **Python** - Used for writing the software to process the data and control the haptic motors.

4. **RealSense SDK** - Provided by Intel and is used for interfacing with the D415 camera. Allows access to depth and other data from the camera.

5. **Haptic Motors** - Output devices that provide haptic feedback to the user.

6. **Stereoscopic Triangulation** - Used to determine depth in a 3D space given the images of two cameras.

7. **AI** - Used for improved object detection.

3.4 DESIGN CONTEXT

1. **Public health, safety, and welfare** - First and foremost, this project will most greatly affect the welfare of visually impaired people who use it by increasing their ability to navigate their surroundings. This can have many effects on them, such as decreasing safety risks and the likelihood of injury, as well as increasing their opportunities, particularly job opportunities, by allowing them to navigate better. One element of our project uses a camera to see what is in front of our user. This might conflict with privacy laws, and the general public's privacy.

2. **Global, cultural, and social** - One cultural consideration we must consider is people's comfort with the cameras, particularly in regard to when the product is used in an area where cameras would not be desired, like a public bathroom or locker room.

3. **Environmental** - How reliable, durable, repairable, and recyclable the project is may have an impact on the amount of waste sent to landfills, toxic substances from the battery in the environment, and on greenhouse gas emissions.

4. **Economic** - If our project helps visually impaired people to better navigate, then they may be better able to participate in the economic system by having jobs and having money to spend, thereby having a positive effect on the broader economy.

3.5 PRIOR WORK/SOLUTIONS

The haptic sleeve creation we are trying to implement has a previous iteration produced in this article. We are taking some of the lessons learned through this project and building on top of it by exploring different iterations of the project. We believe some of the shortfalls of this project pertain to comfort and accurate localization. We have a different idea of going about creating the stereovision wearables and a different iteration of relaying haptic feedback.

- Manuel Zahn, Armaghan Ahmad Khan, Obstacle avoidance for blind people using a 3D camera and a haptic feedback sleeve. arXiv:2201.04453v1 [cs.HC]
- Haptic Feedback testing adequacy for relaying 3D information:
  https://arxiv.org/pdf/2303.16805.pdf

The voice is an existing application that uses sound to relay depth information and is a direct competitor to what we are trying to achieve. Though in one of the research papers regarding feedback sound is much less effective at relaying information compared to using vibration motors.

- The vOIce:
  https://www.nvaccess.org/audioScreen/

3.6 DESIGN DECISIONS

For easier allocation to research, resources, and time, the design was split up into two major project considerations.

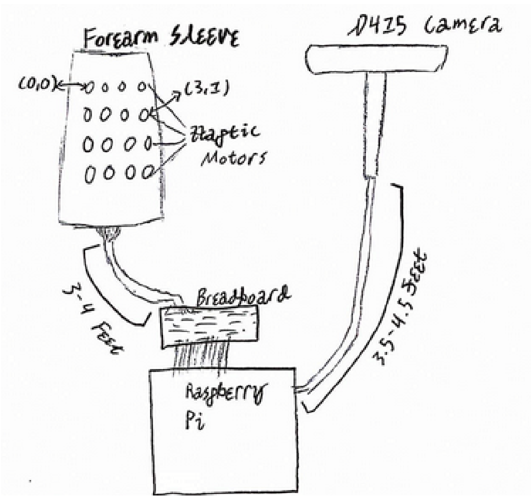
1. The creation of the haptic feedback array.
   (a) Testing the relaying of information using the purchased vibration motors and figuring out the accuracy of said motors in relaying information.
   (b) Design considerations:
      i. Singular sleeve: a singular sleeve of densely populated haptic feedback motors, the drawback being the accuracy of determining and accurately localizing the different vibration intensities and motors.
      ii. Double sleeve: double sleeve where the haptic feedback motors are more sparsely populated, suspecting more accurate but more difficult to wear.
      iii. Back brace: A back brace with multiple motors, This design iteration has several questions since we have yet to do testing on the back. Firstly we need to consider if the back has adequate feel and neurons to determine intensity and motor location.
2. The installation and usage of a depth measuring device.
   (a) We have ordered a Kinect to first get depth data as a testing ground until we order a stereoscopic camera that is wearable.
   (b) Design consideration:

i. D435i camera: this is the most likely path we take regarding a stereoscopic camera due to the existing documentation and accuracy along with its night vision capabilities. The only issue is its wearability.
ii. Snapchat Spectacles: this is one of the options that is currently being considered, one major advantage being its convenience in wearability and worldwide adoption, though it does come with some drawbacks, lacking sufficient documentation and developer support being the main issue, other issues include battery life, accuracy and response time.
iii. Lidar Camera: This was one of our deprecated solutions for achieving depth sensing. We worked on using the iPhone's existing Lidar sensor and tried to send that information but there is a lack of developer support in this avenue. Lidar cameras also have significant drawbacks when it comes to their use in sunny areas along with their power draw.

3.7 PROPOSED DESIGN

So far we have tested a rudimentary implementation of the forearm sleeve, using a sock to mimic the sleeve and placing motors inside. Testing with this device has demonstrated our ability to differentiate between and sense the patterns of vibration in the haptic motor array.

3.7.1 Design 0 (Initial Design)



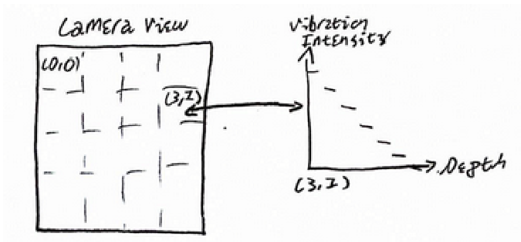


Figure 2

Figure 3: Design 0.

Design Visual and Description The forearm sleeve is the tactile device by which the wearer senses the depth information. The D415 camera is necessary to read the depth information. The cables are used to carry signals, the Raspberry Pi processes information, and the breadboard is a breaker for our signals.

The camera sends depth information, visualized in Figure 2, which is processed by the

Raspberry Pi. The camera's vision is divided into 16 sections, each of which provides depth information for its corresponding haptic motor. The Raspberry Pi processes this information, sending a signal to each section's haptic motor as a percentage of that motor's maximum vibration strength.

Functionality The wearer wears the forearm sleeve on either arm, holding the camera in that same hand. The camera can be pointed around to create a sensation that can be interpreted to know where objects are in the camera's vision relative to its location.

This can be used to walk down a sidewalk or through a cluttered inside room. Objects moving in front of the camera, or the camera moving, creates a wave of changing depth sensations which have been shown to be an acceptable means of communicating visual information.

3.7.2 Design 1 (Design Iteration)

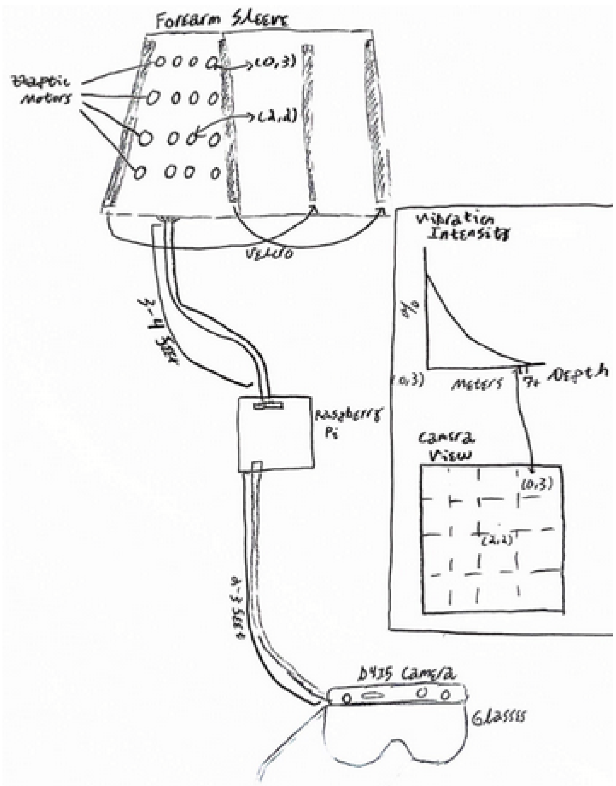


Figure 4: Design 1.

Design Visual and Description Changes to this design include: The forearm sleeve of this design now incorporates a second layer to separate motors and skin, the motors are connected directly to output pins in the Raspberry Pi, the d415 camera is mounted to sturdy glasses on the wearer's head, and the depth information is translated to vibrations along a continuous curve rather than a stepwise function.

1. The forearm sleeve of this design now incorporates a second layer to separate motors and skin.
2. The motors are connected directly to output pins in the Raspberry Pi.
3. The d415 camera is mounted to sturdy glasses on the wearer's head.
4. The depth information is translated to vibrations along a continuous curve rather than a stepwise function.

Functionality These changes decrease complexity, allows the wearer the use of their hand, and gives higher resolution depth information to the wearer.

3.8 TECHNOLOGY CONSIDERATIONS

Several different technology considerations were debated regarding how best to get visual depth data. The main technologies discussed were stereo cameras, lidar, and smart glasses. Smart glasses are simple and intuitive to wear as a user but were quickly discarded as a viable option due to the restricted access of the software that allowed for accessing the depth data. Lidar provided accurate depth data, more so than the stereo cameras. However, it was discarded since getting a system small and cheap enough to be viable in the design was not possible. The stereo camera was the best option of the three, as it provided semi-precise depth data, had a small form factor, and was relatively cheap. Furthermore, they provide color and text data allowing for the possibility of integrating AI for visual detection. With these considerations in mind, a stereo camera was opted for that met the visual requirements.

For the computing device, a cheap but efficient system was desired. Therefore, Raspberry Pi was chosen as it provides enough computational power, and members had previous experience designing systems with them. If it was found that at any point the Raspberry Pi could not provide enough computing power, an Nvidia Jetson would be upgraded too. However, it was calculated that it was unlikely for that to occur.

Regarding the feedback loop for the user interface, the only viable option was haptic motors. An alternative of inducing shocking was suggested, but was discarded as it was outside the scope of our expertise and knowledge to do so safely and effectively. Vibration motors were chosen that produced enough disturbance to be detected, but small enough to create an array and be powered by the Raspberry Pi. Our vibration motors ultimately were chosen from a research paper that was found detailing a similar project to ours.

3.9 DESIGN ANALYSIS

Our design has met our defined requirements based on the most current iteration. The stereo camera was able to interface with the Raspberry PI and deliver continuous data. Computation of the depth map necessary to supply the correct frequency to the motor resulted in 20 times per second intervals, exceeding our set requirement. The vibration motors were then responsive to the outputted signals from the Raspberry Pi.

Moving forward, our design requires alterations mainly in the wearability and maintainability categories. The current system to mount the haptic motor array is rudimentary and requires precise visual placement, which is unrealistic for our user. The wires are currently scattered around, with no housing to protect them. This makes it easy for a wire to come undone and require reinstallment. Thus, more research and design must be put into finding simple solutions for users to equip and remove the system. Furthermore, better software performance can be considered to achieve higher interval cycles.