Team 27

Machine to Human Vision

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27 November 2023

Client	Sami Bensellam
Advisor	Alexander Stoytchev

Sami Bensellam	Project Lead
Alexander Black	Hardware Lead
Jacob Burns	Software Development
Yogesh Chander	Software/Hardware Integration
Jacob Lyons	Component/System Design
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Executive Summary

Development Standards and Practices Used

1. **Agile** - Team planning and management.
2. **Software Frameworks** - openCV, numpy
3. **Engineering Standards** - IEEE 2671-2022, GMSL2 FAKRA, USB 3.1 Type C

Summary of Requirements

1. Implement a stereo-vision setup using two cameras to mimic human vision.
2. Determine the distance an object is from the cameras using depth perception and sensors.
3. Implement a haptic feedback system that communicates to the user the depth observed.

Applicable Courses from Iowa State University Curriculum

- CprE 381
- ComS 227
- ComS 228
- CprE/ SE 185
- CprE 281
- CprE 288 (Roomba Labs)
- ComS 309 (Teamwork)

New Skills/Knowledge Acquired Not Taught In Courses

1. **Production Level Team Collaboration** - Learned in internships, clubs, TA roles, etc.
2. **Hardware Experience** - Undergraduate research, internships

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1 Team, Problem Statement, Requirements, and Engineering Standards

1.1 TEAM MEMBERS

- Sami Bensallam
- Alexander Black
- Jacob Burns
- Yogesh Chander
- Jacob Lyons
- Sergio Perez-Valentin

1.2 REQUIRED SKILL SETS FOR YOUR PROJECT

1. **Leadership** - Project management to ensure staying on task and completing project to specifications.
2. **Hardware Design** - Compact design to ensure practicality of device, skill with haptic sensors and Raspberry Pi will also be necessary.
3. **Software Design** - Python will both be used to control the hardware devices.
4. **Testing** - Efficient and wide-ranging testing to ensure reliability.

1.3 SKILL SETS COVERED BY THE TEAM

1. **Leadership** - Sami, Sergio, Alexander
2. **Hardware Design** - Alexander, Jacob L, Sami, Yogi
3. **Software Design** - Sergio, Jacob B, Sami, Yogi
4. **Testing** - Jacob L, Jacob B, Sergio

1.4 PROJECT MANAGEMENT STYLE ADOPTED BY THE TEAM

Agile management style - open to changes in plans and quick to act on feedback from our client.

To support agile execution, the team will have daily standups, two-week sprints with defined user stories, demos at end of each sprint, and a kanban board to visualize workflow. With the hardware/software components, some waterfall project planning is still beneficial for sequencing dependencies. But overall an agile approach will provide the speed, flexibility, and collaboration needed for success.

1.5 INITIAL PROJECT MANAGEMENT ROLES

- **Sami Bensallam** - Project lead, will be supervising both teams and assisting both teams, along with communication with advisor.
- **Alexander Black** - Hardware lead, component assembly, minute taking.
- **Jacob Burns** - General software development, git repository manager, website maintainer.
- **Yogesh Chander** - Software/Hardware integration, making sure both these elements work together smoothly and quickly.
- **Jacob Lyons** - Component and system design, ensuring each piece of hardware works well on its own and as part of the greater system.
- **Sergio Perez-Valentin** - Software lead, component testing, project management and revisioning.

1.6 PROBLEM STATEMENT

Visually impaired individuals, ranging from partial blindness to complete blindness, find it difficult to perceive objects and surroundings daily. This interference gets amplified when they are put into scenarios they have not encountered before or get disoriented. To mitigate these issues, we are attempting to create a product that can scan an environment and relay vital information to its users. We are attempting to do so in a manner that is intuitive and is representative to that of someone with normal eyesight.

1.7 REQUIREMENTS AND CONSTRAINTS

1. Functional Requirements
   (a) True modeling of surroundings.
      i. Track objects up to 7 meters. **(constraint)**
      ii. Vibration displacement of 16 zones. **(constraint)**
      iii. Distinct frequencies per zone relative to detected distance in mm spans.
   (b) The frequency of data input and output is sufficient for users to stay orientated.
      i. The scanner refresh rate must have a minimum of 15 Hz, preferably over 30 hz. **(constraint)**
      ii. The response time for the user from the time of measurements must be below 200 ms. **(constraint)**
   (c) Device power limitations must stay reasonable for user usage.
      i. Power draws must not exceed 12 watts. **(constraint)**
      ii. Device runtime must extend past 2 hours. **(constraint)**
   (d) Data transfer must be within the bounds of use.
      i. Spatial metrics to the breadboards shall be transmitted via USB.
      ii. Image data must remain for intended use cases and discarded.

iii. There needs to be a user agreement that the system is not 100% reliable and must be used at the user's own risk.

2. Usability Requirements

   (a) Comfortable and intuitive design language.

      i. Easy to assemble and put on.
      ii. Can be worn for extended periods of time.
      iii. Has a sleek, low-profile design that does not stick out.

   (b) Climate, weather, and solid resistance.

      i. Functional in a temperature range of 0 to 100 degrees Fahrenheit. **(constraint)**
      ii. Be IP24 rated - constant handling and splashing from all angles. **(constraint)**

   (c) Consistent and reliable modeling of surroundings.

      i. Rescans of an object must have repeatable measurements with a mean deviation of less than 10 mm. **(constraint)**
      ii. Low visibility (fog, low light, etc.) must not impair accuracy.
      iii. System logging for fast and easy diagnosis and repair.

   (d) Reasonable cost of production.

      i. The first Prototype must not exceed $1000 **(constraint)**

3. Resource Requirements: See 1b

4. Qualitative Aesthetics Requirements: See 2aii

5. Economic/Market requirements: See 2di

6. Environmental Requirements: See 2b

7. UI requirements: See 2ai

8. Performance Requirements: See 1b

   (a) Must output to the user at least 15 times each second. **(constraint)**

9. Legal Requirements: See 2diii

10. Maintainability Requirements: Not needed

11. Testing Requirements: See 2ciii

1.8 ENGINEERING STANDARDS

Below are the identified engineering standards required for our project:

1. **IEEE 2671-2022** - This is the IEEE Standard for General Requirements of Online Detection Based on Machine Vision in Intelligent Manufacturing and is needed to standardize transmission processes, data formats, and quality standards for applications of machine-to-human vision.

2. Connection Standards:
    (a) **GMSL2 FAKRA** - Used for the transmission of video out of the camera.
    (b) **USB 3.1 Type C** - Used on the outside of the device for charging and other data transmission.

1.9 INTENDED USERS AND USES

The main beneficiary of our project is targeted toward total blindness users, with a partial utilitarian use for partial blindness and other spatially impaired users. Such users will use the product to create mental images of objects and surroundings that will allow them to navigate within said environment. Expected use cases are:

1. **Navigating Hallways** - Guide the user through hallways, corridors, and tight spaces to prevent collisions with walls or furniture.
2. **Sidewalk Obstacle Avoidance** - Detect objects on sidewalks, such as parked cars, street signs, or pedestrians.
3. **Park Exploration** - Enhance outdoor experiences by identifying rocks, trees, and other features for the user.
4. **Office Navigation** - Assists in locating restrooms, break areas, and other sections of an office.
5. **University Navigation** - Guide the user by helping to identify buildings and entrances.

2 Project Plan

2.1 TASK DECOMPOSITION

Two teams were created, software and hardware, allowing for specialized task decomposition. Team members were assigned a team based on strengths and task requirements.

1. **Software** - Focus on data filtering and depth algorithms.
   (a) Create a python file that takes in stereo camera input and transforms it into depth data.
   (b) Research and select a framework that suits our software requirements.
   (c) Convert depth input into a 4x4 grid.
      i. Use openCV to partition the depth data.
      ii. Take each partition's largest value.
      iii. Take the previous value of the partition to avoid any false values.
   (d) Create code that sends a signal to haptic feedback motors.
      i. Convert Depth Data from (0.5m-7m) to a intensity value between (0-255).
      ii. Identify GPIO port location to transmit for software PWM.
      iii. Take the take the intensity value and transmit that value to the GPIO port.
   (e) Create user agreement.
2. **Hardware** - Focus on haptic motor array and housing of devices.
   (a) Research and select a framework that suits our software requirements.
   (b) Construct and test haptic motor array.
      i. The haptic motor array will be a 4 x 4 matrix of haptic motors embedded into both a forearm sleeve and back brace.
   (c) Construct and test stereoscopic camera housing.
      i. The stereoscopic camera will get depth information from wherever the wearer is looking. This device may be either handheld or placed on the wearers head and secured with headgear.
   (d) Construct and test control unit.
      i. A central unit will take the depth information and vibrate each motor at the necessary intensity. This will be done using a Raspberry Pi.
   (e) Battery
      i. Selecting a battery that will be able to:
         A. Run for 2 hours plus.
         B. Able to handle the power draw from 16 vibration motors, onboard processor, and stereo camera.
         C. Small and wearable form factor.
         D. Safe and reliable.

(f) Assemble device, connecting motor array, camera, and control unit.

i. All three components will be connected in order to construct the final device. Information from the camera will go to the control unit and then finally to the haptic motor array.

(g) Construct test environment.

i. Create an obstacle course where the person needs to navigate using the System in detecting different obstacles. Both inside and outside courses.

(h) Run field testing.

i. We will conduct extensive and thorough testing in several scenarios.

(i) 3D Printing

i. Creating a housing for the stereo Camera such that the user will be able to to use it.

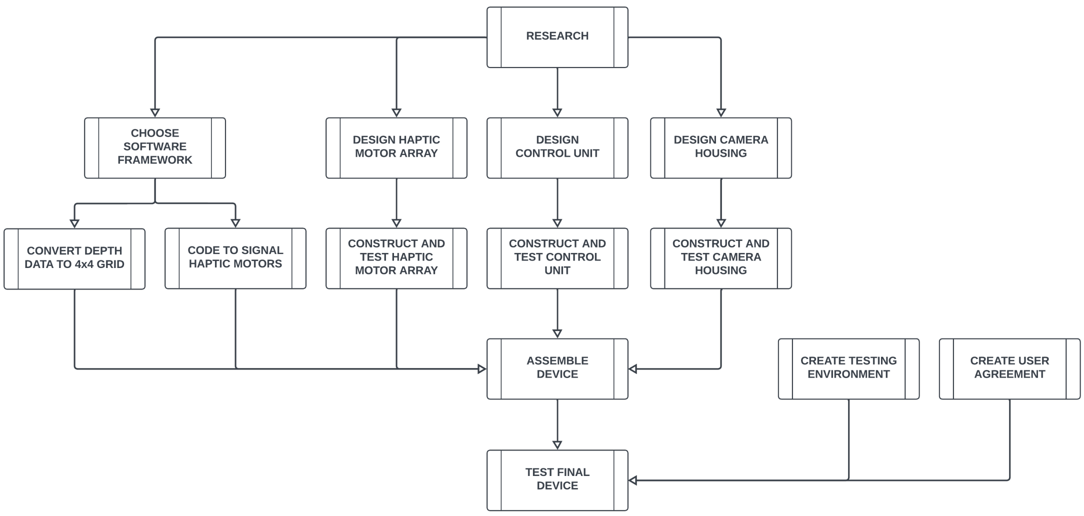


Figure 1: Task Dependence Graph.

2.2 PROJECT MANAGEMENT/TRACKING PROCEDURES

We will use Agile Development methodology with 2-week sprints. The key advantages of agile for this project are:

1. **Iterative development** - Requirements and solutions can be refined incrementally through build-test-feedback loops. This allows incorporating user testing insights as they emerge rather than fully defining everything upfront.

2. **Adaptability** - Agile is better suited for handling uncertainty and changes that often arise with novel hardware/software projects like this. Plans can be adjusted as needed.

3. **Early value** - Agile prioritizes working software over documentation, allowing demoable prototypes early on rather than waiting for everything to be built. This enables validation.

4. **Collaboration** - With its emphasis on close teamwork and user feedback, agile promotes the cross-functional collaboration needed in this multi-disciplinary project.

5. **Focus** - Breaking work into 2-week sprints maintains focus on the current priorities rather than getting overloaded by the full scope.

The group will use Git for software management, two weekly meetings for progress reports (alt. online at Webex or Discord), Discord for link transfer and voice communication, Snapchat for quick text communication, and Google Drive for file transfer and collaboration.

2.3 PROJECT PROPOSED MILESTONES, METRICS, AND EVALUATION CRITERIA

Several key milestones have been identified for our project to ensure proper and timely progression towards our project objective.

1. Haptic Feedback Motors
   (a) Connecting LED light with the raspberry pi and being able to run a script that lights the LED on/off.
   (b) Connecting Haptic feedback motor to the raspberry pi and being able to turn vibrations on/off.
   (c) Controlling haptic feedback motor intensity using python script.
   (d) Controlling 16 haptic feedback motors using python script.
   (e) Connecting the haptic feedback motors to a wearable device.
2. Stereo Camera
   (a) Connecting the Kinect to get depth data.
   (b) Partitioning that data into 16 values with the highest value in each partition.
   (c) Getting that information to run at 16hz in a python script and relaying that information to the vibration motors.
   (d) Getting a proof of concept functional and ordering a d435i depth sensing camera.
   (e) Transforming the existing system to take depth information from d435i depth sensing camera instead.
   (f) Housing the camera in a 3d printed goggle and a flashlight.
3. Speaker (Low priority)
   (a) Purchasing a speaker and successfully getting it to play sounds controlled from our board.
   (b) Setting up a button and a button listener in a python script that is able to play a sound when button is pressed.
   (c) Creating a text to speech converter that reads out words.
   (d) Getting d435i RGB information and using an existing api to list all objects detected.
   (e) Getting the speaker to list all of the objects seen in the camera.

2.4 PROJECT TIMELINE/SCHEDULE

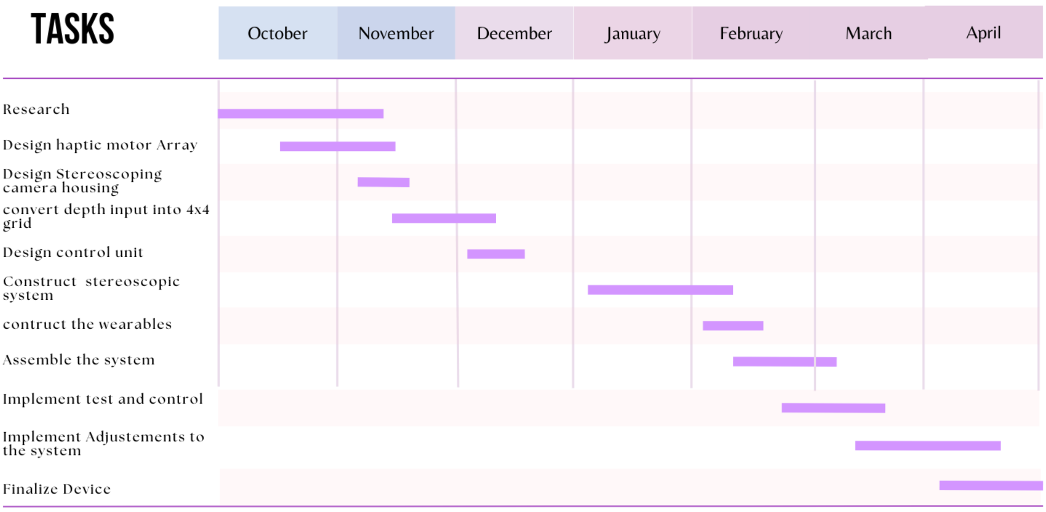


Figure 2: Gantt Chart.

2.5 RISKS AND RISK MANAGEMENT/MITIGATION

Agile project can associate risks and risk mitigation with each sprint.

1. Vibrations via haptic motors are a non-functional method of communicating depth information (0.5).
   (a) In the event that haptic motors are non-viable for our project needs, whether that be because the motors interfere with each other or it is simply not interpretable by the wearer, we will instead pivot to a pressure based communication system. Research has shown this to be an effective method to communicate environmental information.
2. Stereoscopic depth sensing is not able to communicate depth information to the wearer at an acceptable framerate or accuracy (0.4).
   (a) In this event, we will instead use a LIDAR based system.
3. The Raspberry Pi is incompatible with our project specifications (0.7).
   (a) In the event that the Raspberry pi is not able to compute the data coming in from the stereo camera we will purchase an equivalent device that uses faster processing.
4. The device cannot be miniaturized to be wearable (0.3).
5. The device degrades after donning and doffing (0.6).

(a) It will be important to ensure the haptic motors are secure and stay in one position on the wearer's body. If this is an issue we will create a plastic cover for the motors that can be sewn into the fabric to keep the motors in place.

2.6 PERSONNEL EFFORT REQUIREMENTS

Requirement	Hours Required	Explanation
Research and select a framework.	10	We will need to ensure that we select a sufficient framework for our needs.
Design haptic motor array.	15	We need to make sure that the vibrations are given as intended.
Design stereoscopic camera housing.	15	Needs to fit securely.
Convert depth input into a 4x4 grid.	30	Use openCV to partition the depth data.
Design control unit.	30	Must connect the camera and haptic motors without error.
Construct haptic motor array.	30	Building multiple prototypes.
Test haptic motor array.	20	Ensure it works optimally.
Construct stereoscopic camera housing.	15	Needs to fit well and be lightweight.
Create code that sends signals to haptic motors.	30	Connect the software to the motors.
Construct control unit.	30	Needs to be built to our requirements.
Implement and test control unit.	20	Must send and receive data without discrepancies.
Assemble device.	40	Bringing all of the pieces together.
Test device.	40	Testing with multiple challenges and people.
Create user agreement.	3	Writing an official user agreement for liability.

2.7 OTHER RESOURCE REQUIREMENTS

1. Tatoko 10 mm x 3 mm Haptic Motors
2. Intel D435i Stereoscopic Camera
3. Raspberry Pi
4. Breadboards, 16 Gauge Wire, heat shrink

5. Forearm sleeve (Unit to hold the haptic motor array)
6. 3D Printer
7. Battery Bank

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.

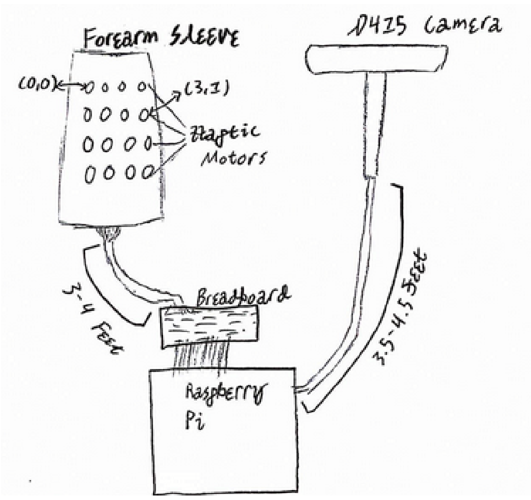
1. The creation of the haptic feedback array.
   (a) Testing the relaying of information using the purchased vibration motors and figuring out the accuracy of said motors in relaying information.
   (b) Design considerations:
      i. Singular sleeve: a singular sleeve of densely populated haptic feedback 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)



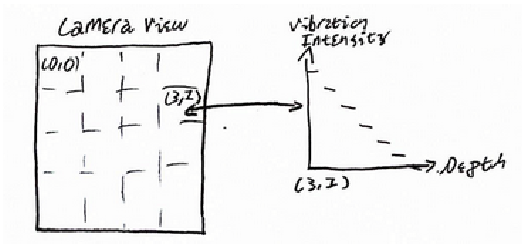


Figure 2

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)

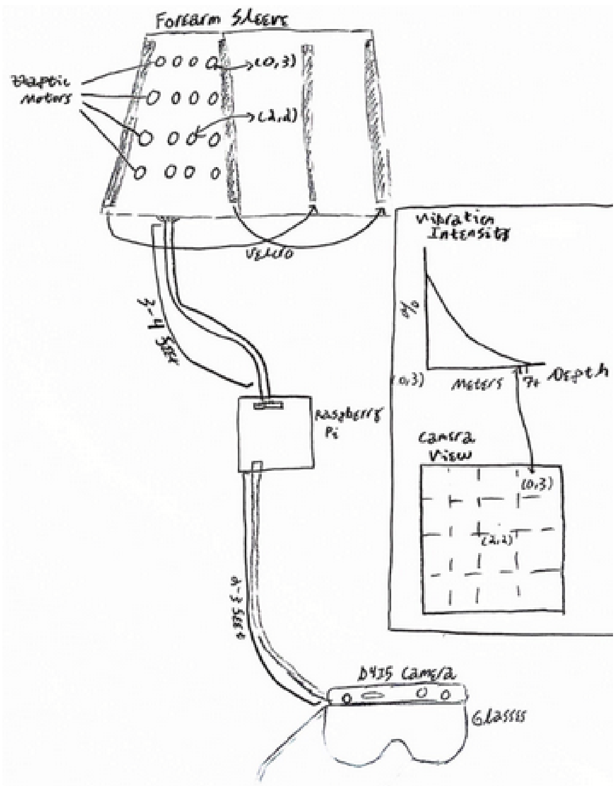


Figure 4: Design 1.

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.

4 Testing

Our Machine to Human Vision project contains many variables outside our control of feasible testing. Each user will be of different proportions, have different sensation receptors, and variaying levels of ability to understand the incoming information from the haptic motors. That said, the following testing methods will attempt to mitigate any variability that might be encounterd to procude the most linear results amongst users.

4.1 UNIT TESTING

1. **D435i Camera** - The camera will be tested to ensure it can generate accurate depth information with low latency and at a framerate of 30 fps. We will test it to ensure it registers important objects, such as a pole, even if they do not take up a significant portion of the camera's vision. This testing will be done using python script and having a team member validate the depth data retrieved by the camera.

2. **Raspberry Pi** - We will test the raspberry pi using a multitool to ensure it can power itself, the motors, and the camera at the same time. We will also test it to ensure it can operate at 30 fps, reliably vibrate the motors as desired, and accurately interpret the camera's depth information. This will be done via human validation.

3. **Haptic Motor Array** - The haptic motor array is the unit that will require the most testing. We will test different arrangements of the haptic motors, such as a pure 4 x 4 grid or a 4 x 4 grid that widens at the bottom in order to determine which is the easiest to navigate with. Effectiveness testing will be done by having a person wear the array and attempt to navigate using it. We will also test different fabrics and fabric thicknesses for the sleeve to find a design that is easy to navigate with but does not damage the wearers skin. We will test each motor to ensure they vibrate at the same strength using an accelerometer.

4. **Battery Pack** - We will test our battery pack using a multimeter to ensure it can generate at least 4.5 amps to power the Raspberry Pi, camera, and haptic motors.

4.2 INTERFACE TESTING

In our project, there is an interface where the stereo optic camera is connected to the hardware that controls the haptic feedback motors. In our current prototype, we are interfacing an Xbox Kinect and a Raspberry Pi 3. In our later prototypes, we will interface a real stereo optic camera and a Raspberry Pi 4. In order to test the interface between the camera and raspberry pi, there will have to be a physical connections test, where it is checked to make sure the camera is properly mounted onto the raspberry pi. There are also raspberry pi terminal commands that return whether or not there is a camera module connected to the pi which can be used for interface testing.

There is also a physical wire connection between the pi and the haptic feedback motors which will have to be tested. This will have to be tested through the software and the hardware. The software test will entail making sure the proper amount of voltage is sent to each haptic motor based on the data from the camera. The hardware components like the GPIO pins and haptic motors will have to be tested for proper wire connections by running current through the wires via a raspberry pi python script to make sure the haptic motors and GPIO ports are properly functioning.

Another interface that will need to be tested will be the connection between the transmission of data between the camera and the raspberry pi. A software test will have to be written where we know the depth of a set of objects in front of the stereo optic camera, and we must see if that data is properly received and processed within our raspberry pi program that handles outputs to the haptic motors. The GPIO pin outputs will also be tested by turning them on or off from a raspberry pi script.

4.3 INTEGRATION TESTING

Four main units have been identified as crucial during the integration process. Each unit plays a critical role in the overarching project goal, and undergo extensive requirement testing. They are D435i camera for vision, Raspberry Pi for compute, haptic motor array for feedback, and battery pack for power.

The integration process can be broken down into three critical integration paths. No specialized tools are needed to ensure proper integration outside the assumed.

1. **Compute Vision** - The compute vision path seeks to integrate the D435i Camera module with the Raspberry Pi. The camera provides real time depth maps and captures that allows us to map an environment, while the Raspberry Pi provides the compute power to process the data. The two units will be connected with a USB C cable, providing 5 Gbit/s signaling rate over 1 lane using 8b/10b encoding (nominal data rate: 500 MB/s). The physical connection ensures a quick and reliable connection despite external factors. The D435i Camera scans will all be processed through software on the Raspberry Pi. Therefore, the main form of testing will be performed through software unit tests. Main unit tests that will be used involve:

   (a) Receiving a correctly formatted data sequences from the D435i Camera.
   (b) Splitting depth maps into a cell grid to represent the Haptic Motor Array.
   (c) Converting a cell into a single representative depth point.

   Other unittests that may be required are:

   (a) Compression of depth maps for simpler processing.
   (b) Depth map formatting of values.

2. **Feedback from Compute** - The feedback from compute path seeks to integrate the Haptic Motor Array with the Raspberry Pi. The Raspberry Pi provides a formatted frequency response array, while the Haptic Motor Array relays those frequencies in a physical manner to the user. The two units will be connected physically to provide both power and data through a single wire. The software aspect will be assumed correct, as the Compute Vision path will test the Rasberry Pi to always provide a correct frequency response array. Therefore, the main form of testing will be performed through hardware unittests. Main unittests that will be used involve:

   (a) Stable connection between motors and board.
   (b) Instant motor frequency changes based on incoming data from Raspberry Pi.
   (c) Secure mounting of components to a wearable vest that allows for the previous.

3. **Power System** - The power system path seeks to integrate each of the other units to the battery pack to provide mobile power. Each unit requires a unique power output and connection. Therefore, the main form of testing will be performed through hardware unit tests. Main unit tests that will be used involve:
   (a) Battery endurance tests to ensure prolonged use during high compute periods.
   (b) Correct amps and voltage output for each unit.
   (c) Overheating and safety testing.

4.4 SYSTEM TESTING

1. **Unit Tests** - As mentioned in 5.1, we will test the camera, motor array, battery, and the Raspberry Pi to ensure they all work. Unit tests can also be used to ensure the end-to-end operation of the system. One way to do this is by comparing the final vibration levels of the motor (both by feeling them and looking at the quantitative vibration data in the program controlling the motors) to different environments that the camera is looking at to ensure that they all correspond.
2. **Interface Tests** - We will test the outputs of our conversion of the depth data and the and verify that it is the same as the inputs to our haptic motor script to ensure that the data is being transmitted correctly. In addition, we will test that each component is receiving the voltage that it needs by using a multimeter.
3. **Integration Tests** - One way we will test the integration of the system as a whole is by trying to use the system as our target audience would, by attempting to navigate in a room (and other places, such as outdoors, through a hallway, etc) with the device as opposed to our eyes. This ensures the device meets requirements by way of us knowing that the device will be useful to its target users.

4.5 REGRESSION TESTING

1. **Regression Test Cases** - We will develop a comprehensive set of regression test cases that cover all critical features. These test cases will ensure that the depth data is accurately converted and sent to the haptic motors at the correct intensity.
2. **Continuous Integration** - Introducing a continuous integration pipeline will ensure that no faulty code will be committed to our GitLab repository. CI allows us to run automated regression tests whenever there is a change in the repository. This will help to mitigate the risk of newly added code breaking any currently operational functions.
3. **Data Input/Output testing** - Confirm that the Raspberry Pi is able to trigger the haptic motor vibrations with low latency. This can be done by ensuring that the response time of the device is below 200 ms. It is important to confirm that response time is not affected by changing code or adding additional features.

4. **Battery Testing** - We will ensure that battery consumption does not increase greatly as the device changes and improves. This can be done by monitoring the energy usage of the battery pack.

4.6 ACCEPTANCE TESTING

To ensure a more comprehensive approach to our project deliverables, we will establish concrete, measurable objectives that encompass a variety of specific testing scenarios. This will include tests where the user is tasked with identifying distinct objects, reflecting the product's capability in object recognition. Furthermore, we will evaluate the user's ability to successfully navigate through a meticulously designed obstacle course, which will serve as a practical demonstration of the product's interactive navigational features.

The paramount indicators of our success prior to releasing the final product will be its reliability and usability. To gauge reliability, we will conduct rigorous and repeated testing under varying conditions to ensure consistent performance and stability. Usability metrics will be derived from user testing sessions, where feedback on the product's interface and interaction design will be collected and analyzed. This feedback will inform iterations that aim to create an intuitive and user-friendly experience.

The structured objectives and precise metrics established for this project are intended to ensure that the quality standards are not merely met but surpassed. The emphasis on these elements is to produce a product that demonstrates consistent reliability across various operational environments and is marked by a significant focus on user-centric design principles.

4.7 SECURITY TESTING

Every component and software aspect of this project is contained within a close loop of connections. Therefore, unless physical access to the device is achieved (which is outside our scope of control), the product is secure from any malicious intent.

4.8 RESULTS

The first tests conducted were tests to determine the haptic feedback vibration motors' ability to reliably transmit information. For the first testing we used an oscilloscope to transmit different Voltages and tested the ability for the user to identify the different vibrational intensities. Our results were pretty unreliable. But we had issues with the testing as the project was in it's infancy and we did not have a proper prototype leading to inaccuracies in the results.

We were also able to create a sleeve where we connected the haptic feedback motors and conducted a series of tests where we measured the user's ability to differentiate the different vibration intensities along with the differences in the ability for a user's ability to identify the motors. The testing with this bench came out with promising results as the user was able to reliably identify the vibration intensity with a margin of error of +/-10%.

We have conducted a series of tests with the new adafruit hat where we connected the haptic feedback motors to the adafruit hat and tried to replicate the same tests conducted using the native GPIO ports of the raspberry pi. The tests conducted came out to be unreliable leading us to walk back and refine our connections, specifically the soldering of the board, as it is a main concern in terms of the reliability of the Adafruit hat.

We were able to create our first prototype using a kinect along with 2 haptic feedback motors. thus we were able to have a proof of concept where we got a functional testing bench. The kinect was able to identify objects and relay that information to the motors but we did experience some difficulties when it comes to reliably transmitting that information. Reliably identifying the motors that were running and the response time.

5 Implementation

5.1 OVERVIEW

Our next goals are to expand the prototype's scope to operate with more motors and more subdivisions in the camera's vision. Our prototype currently operates with 4 motors, and we will next double it to operate with 8, and then again to our desired final number of 16 motors. Each of these expansions is a proof of concept milestone that allows us to know our design is scalable. Each of these expansions will also demand a doubling of the raspberry pi's computing power and an increase in power draw. Alongside these prototype developments we will be making a number of ergonomic improvements to allow for easier testing.

1. The sleeve, worn on the user's forearm and holding the motor array, will be finished. Once It has been completed and is capable of adjusting and securely holding the motor array we will sew each motor into place on the sleeve.

2. Once we have proven our design works at 16 motors, we will permanently connect our motors to the Raspberry Pi via soldering. This permanent connection will allow for easier testing and more variable prototype design.

3. The wires from the motor array will be bundled into a cable when the array is soldered to the Raspberry Pi. Turning 32 wires into 1 cable will make the system significantly more manageable is a large step towards establishing wearability.

4. The d435i camera will be mounted upon a pair of safety glasses. The cables from it and the Raspberry Pi will run into a backpack where the Raspberry Pi is located in a secure container.

Following the above breakthroughs, we intend to shift our focus to testing and improving our prototype's accuracy. This testing will be invariably tied to the development of our project, as it is this testing that allows us to improve it's abilities. It will largely be conducted by a user using our device to either analyze a fixed We will test many different designs for our haptic motor array in an effort to find the design that most intuitively conveys depth information. Additionally, we will work to improve the algorithm that determines how strong a motor should vibrate according to the depth mapping, so that the wearer is able to draw as much information from the changing vibrational patterns as possible.

Further areas of improvement include improving the camera's accuracy, and ensuring the most necessary information is always considered by our image analyzing algorithm. Alongside testing the performance of our individual components we will test the entire prototype in obstacle courses to ensure operational efficiency and that each component works as intended and in tandem with the other components. Once we have developed a prototype capable of navigating through a variety of obstacle courses and can promptly and accurately respond to changes in its environment we will begin the next stages of our project.

6 Professionalism

6.1 AREAS OF RESPONSIBILITY

IEEE Standard: To uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities.

1. To hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment.
2. To improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems.
3. To avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist.
4. To avoid unlawful conduct in professional activities, and to reject bribery in all its forms.
5. To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others.
6. To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations.

Area of Responsibility	**Definition**	**NSPE Canon**	**Similarity to IEEE Standard**
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence.	Perform services only in areas of their competence; Avoid deceptive acts.	Uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities. To hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment.

Financial Responsibility	Deliver products and services of realizable value and at reasonable costs.	Act for each employer or client as faithful agents or trustees.	Avoid unlawful conduct in professional activities, and reject bribery in all its forms.
Communication Honesty	Report work truthfully, without deception, and understandable to stakeholders.	Issue public statements only in an objective and truthful manner; Avoid deceptive acts.	Seek, accept, and offer honest criticism of technical work, acknowledge and correct errors, be honest and realistic in stating claims or estimates based on available data, and credit properly the contributions of others.
Health, Safety, Well-Being	Minimize risks to safety, health, and well-being of stakeholders.	Hold paramount the safety, health, and welfare of the public.	To hold paramount the safety, health, and welfare of the public, strive to comply with ethical design and sustainable development practices, protect the privacy of others, and disclose promptly factors that might endanger the public or the environment.
Property Ownership	Respect property, ideas, and information of clients and others.	Act for each employer or client as faithful agents or trustees.	Avoid real or perceived conflicts of interest whenever possible, and disclose them to affected parties when they do exist.
Sustainability	Protect environment and natural resources locally and globally.		Strive to comply with ethical design and sustainable development practices.
Social Responsibility	Produce products and services that benefit society and communities.	Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.	Conduct themselves with integrity, responsible behavior, and ethical conduct in professional activities to enhance the honor, reputation, and usefulness of the profession.

6.2 PROJECT SPECIFIC PROFESSIONAL RESPONSIBILITY AREAS

1. **Work Competence** - This standard is extremely applicable to our project since without a high standard of work ethic, timeliness, and professionalism, this project will not be successful and the final product will be riddled with many bugs or other shortcomings which would represent a failure to deliver the intended device. This standard is applicable to any team responsible for delivering a product or service. On this standard our team has delivered high quality results with vigorous note taking over all meetings, vehement research on required components, and group brainstorming/work sessions.

2. **Financial Responsibility** - This standard applies to our project since our goal is to create a device for sight impaired people to use, and giving this device a high price would make it more difficult for our intended users to use this product. We have been good at conserving our financial resources to build this device by not wasting money on unnecessary components for our project.

3. **Communication Honesty** - This standard is applicable to our project since honesty between our team and the client or advisors is essential to a better development process for this product. Our team has been good at following this standard since when meeting with our client and our advisors, we always give truthful progress reports and we make sure our client and advisor understand the progress being made on our project.

4. **Health, Safety, Well-Being** - This standard is applicable to our project since our product is aimed to help sight-impaired people navigate the world freely without injury. If we don't consider the health and safety of our clientele when making this product, we go against the whole purpose of our product. We have enforced this standard very well by studying many components of our design to make sure the client has a good user experience including making sure objects are properly recognized by our stereoscopic camera, and making the user experience pleasant with the haptic motors that are worn by our users.

5. **Property Ownership** - This standard is applicable to our project since our design involves using a camera to pick up objects in front of our users which could be seen as an invasion of privacy. Our design nullifies this by making sure that the images that our camera picks up are never saved or disseminated to other sources.

6. **Sustainability** - This standard could be applicable for our project if we use materials that have negative environmental implications. In our design we are not using materials that have negative environmental effects. In fact many components of our design are widely used in the industry and are generally accepted for product creation.

7. **Social Responsibility** - This standard is very applicable to our project since this product is being created for vision impaired individuals which would be a tremendous benefit for society since this would allow vision impaired individuals to assimilate further into society. Our group's maintained development of this product shows that we have followed this standard to a high degree.

6.3 MOST APPLICABLE PROFESSIONAL RESPONSIBILITY AREA

The most applicable professional standard to this project would be the health, safety, and well being standard. This standard is at the essence of this product due to this product being for vision impaired individuals, so health, safety, and well being of those certain individuals is at the forefront of all of our design situations. We will make sure to evaluate potential risks associated with the system, such as incorrect object detection or delayed feedback, and implement measures to mitigate these risks. We will also consider ergonomic design and user interface principles to ensure that the system, particularly the haptic motors, does not cause discomfort or harm during use.

7 Closing Material

7.1 DISCUSSION

Our project aims to assist visually impaired individuals in navigation through the development of a wearable device. The Kinect used in our prototype did not meet our requirement of tracking objects up to 7 meters away, however, the D435i stereoscopic camera will meet this requirement. The prototype proved that haptic motors were viable, but did not meet the vibration displacement requirement of 16 zones. The frequency of data input and output(refresh rate of 15 Hz) has been met in our prototype and must be maintained throughout further development.

Power limitations have not been met, as no prototype has operated off a battery for extended periods of time. Data transfer has been within bounds of use as the image data is purely used for object detection in our prototypes. The design's comfort and climate requirements have only been partially met as a fully wearable device has not yet been constructed. The first prototype's cost of production did not exceed $1000.

7.2 CONCLUSION

Our work has focused on developing a system to assist visually impaired individuals in navigating. The product comprises three main components: a stereoscopic camera, a haptic feedback array, and a bridge for computing. Our goals involve enhancing navigation and safety for visually impaired users through a wearable device. We intend to meet all of our listed requirements and complete an obstacle course to show the effectiveness of the device. Our plan of action involves purchasing the D435i camera and increasing the number of motors implemented to the complete 4x4 grid.

Moving forward, it is essential to test every portion of the device. When building our prototypes, we found it essential to solder correctly and ensure the connectivity of our wires. The prototype using a Kinect and two haptic feedback motors provided a testing bench, offering a proof of concept. However, there were slight challenges with identifying running motors. To achieve our goals effectively, future iterations should focus on reliable connections and address challenges in haptic feedback transmission. Continuous testing and refinement are crucial to ensure a seamless user experience.

7.3 REFERENCES

1. Manuel Zahn, Armaghan Ahmad Khan, Obstacle avoidance for blind people using a 3D camera and a haptic feedback sleeve. arXiv:2201.04453v1 [cs.HC]

2. Haptic Feedback testing adequacy for relaying 3D information: https://arxiv.org/pdf/2303.16805.pdf

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

7.4 APPENDICES

7.4.1 Team Contract

Team Procedures

1. Regular team meetings are scheduled to take place every Friday at 11:00 am. The location will be Parks Library unless otherwise relocated due to conflict or required activity. Additional meeting times may take place with the team or sub-teams as work ramps up.

2. For hour by hour communication, a mobile messaging app will be used to communicate quick update. For day by day communication, a discord server will be established to maintain long-term communication and an events calander. Logs and documentation will be kept in a shared Google Drive folder. Development tasks and issues will be tracked using GitLabs bultin issues board.

3. Ideally, a consensus amongst the team will be attempted; but if unable to achieve in a reasonable amount of time, a majority vote will be held. Within individual sub-teams, a consensus must be reached.

4. At each regular event, a minutes recorder will be chosen to log details for record keeping. The minutes will be added to a Google doc and updated after each team meeting.

Participation Expectations

1. Every member is expected to attended each scheduled meeting unless otherwise communicated before hand. Arrival to each meeting should happen 5 minutes prior to the designated start time. Participation is expected from each member respective to their role.

2. All assignments and preparation must be completed by the designated deadline. All group members should keep a timeline and make steady progress on their work, while maintaining communication on progress through the proper communication methods.

3. Expected level of communication will be relative to the conversation is question, but is expected to be handled in a timely manner and in good standing, i.e. respectfully and detailed. Delays in responses to team communication must not be exceed 24 hours with the exception of unforeseen emergencies.

4. Each member should abide by the group's decisions, and perform their tasks to the best of their ability. Completing assigned tasks to given specifications is required. It must be communicated to the team if a member is unable to do so.

Leadership

1. Leadership roles for each team member:

   - **Sami Bensallam** - Project lead, will be supervising both teams and assisting both teams, along with communication with advisor.
   - **Alexander Black** - Hardware lead, component assembly, minute taking.

- **Jacob Burns** - General software development, git repository manager, website maintainer.
- **Yogesh Chander** - Software/Hardware integration, making sure both these elements work together smoothly and quickly.
- **Jacob Lyons** - Component and system design, ensuring each piece of hardware works well on its own and as part of the greater system.
- **Sergio Perez-Valentin** - Software lead, component testing, project management and revisioning.

2. During team meetings, the team will check on the progress of each team member. If a team member is struggling, another member of the team will be assigned to assist the struggling member. If problems still persist, a TA or outside consulting will be called upon.

3. Gitlab issues and commits will be used to monitor the contributions of all team members.

Collaboration and Inclusion

1. Skills, expertise, and unique perspectives each team member brings to the team:
    - **Sami Bensellan** - Experience with both hardware and software, with a stronger focus in software engineering.
    - **Alexander Black** - Experience with hardware from undergraduate research brings a hardware focus to the team as a Computer Engineering major.
    - **Jacob Burns** - Experience with software and understanding of hardware. Familiar with numerous programming languages and databases.
    - **Yogesh Chander** - Experience with circuitry, embedded systems, and algorithms from major related courses. Further experience in web development.
    - **Jacob Lyons** - Experience with leadership from residential councils and being a TA, hardware design from CprE classes, experience with file systems and wireless communications from research internships.
    - **Sergio Perez-Valentin** - Experience with software workflows and high level conceptualization of program systems. Experience with Artifical Intelligence and machine learning algorithms. Extensive experience with unit testing and failure prevention.

2. The team will ensure each member is given a channel to voice their ideas during meetings. All ideas will be respected and discussed.

3. If a team member experiences collaboration or inclusion issues, it should be brought to the attention of the other members within the group. A solution that ensures the team member can work effectively will be attempted to be found. If a team member is not comfortable voicing their concerns, they should consult with the TA.

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
    (a) Implement a stereo-vision setup using two cameras.

   (b) Determine the distance an object is from the cameras using depth perception and sensors.
   (c) For each team member to expand their skill sets as they complete their tasks.

2. Individual assignments will be given to respective team member that is determined best suited for said assignment. However, proper distribution of work load will be accounted for. Any task requiring more than one member will be grouped into a sub-team task.

3. Meetings must stay project-related. Dedicated channels, such as the Discord server, are reserved specifically for the project. Any non project-related subjects must be held outside the scope of the project.

Consequences for Not Adhering to Team Contract

1. If a team members does not adhere to the stated contract, a meeting will be held to discuss the behavior.

2. If issues persist, it will be notified to the TA and a plan will be worked out. Regarding work, the other team members will redistribute the members work to ensure the project stays on time.

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a *I participated in formulating the standards, roles, and procedures as stated in this contract.*

b *I understand that I am obligated to abide by these terms and conditions.*

c *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*

Sami Bensellam	DATE 9/8/2023
Alexander Black	DATE 9/8/2023
Jacob Burns	DATE 9/8/2023
Yogi Chander	DATE 9/8/2023
Jacob Lyons	DATE 9/8/2023
Sergio Perez-Valentin	DATE 9/8/2023