BU College of Engineering

Boston University
Electrical & Computer Engineering
EC464 Capstone Senior Design Project

User's Manual

OPTICLE

Submitted to

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by

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Opticle

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User Manual

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Executive Summary

Visual impairment impacts millions of people all over the world annually. It has a significant impact on individuals, affecting their quality of life, independence, and mobility. Current mobility aid solutions are limited in detecting off-ground obstacles, do not provide semantic information, and are not always suitable for all age groups. To address this issue, we propose Opticle, a wearable technology that detects obstacles in an outdoor environment with a depth-sensing AI camera and alerts users when any immediate obstacle is detected with haptic feedback and auditory output. The user will wear a chest mount with a camera in the center, a wrist mount with a linear resonant actuator, and bone conducting headphones. Our hope is to provide a solution that allows visually impaired individuals to feel more confident mapping their environments and maintaining their independence when navigating indoor and outdoor areas.

1 Introduction (Author: Jami)

According to The International Agency for the Prevention of Blindness (IAPB), approximately 1.1 billion people globally were living with vision loss in 2020, with 43 million people blind, and 295 million people having moderate to severe vision impairment [1], a significant number of impacted individuals. The health consequences of vision impairment extend beyond just affecting the visual system of those who experience it. There is an increased risk of injuries, as well as an impact on mental health, cognition, social function, employment, and educational attainment. An individual's quality of life, independence, and mobility are also affected [2]. Specifically, with challenges related to mobility, visually impaired individuals have a difficult time in their daily lives walking down the street without colliding with obstacles. Because of these challenges, individuals are less prone to traveling independently.

Currently, the most used mobility aid today is the white cane, which uses physical contact to navigate environments. Although it is practical, it is limited in the detection of off-ground obstacles and in providing semantic information for the user. There are also situations where limiting physical contact is best, such as in crowded areas with many pedestrians. In addition, canes can pose a danger to the user, as they can get stuck in cracks and uneven surfaces [3].

To address this issue, Opticle provides a wearable solution that alerts the user when immediate obstacles are detected in a predetermined region of space. Opticle comprises a wearable chest mount with a camera mounted in the center, a wearable wrist mount with a linear resonant actuator attached, and bone conducting headphones. Our system detects obstacles in an indoor and outdoor environment with a depth-sensing AI camera and alerts users when any immediate obstacle is detected with haptic feedback and auditory output. The overall system has a battery life of 1.5 hours. The system features two modes: mode 1 for the haptic feedback system only or mode 2 for auditory feedback in addition to haptic feedback, allowing the user to choose their preference when deciding what information they would like to receive. Haptic feedback informs the user if there is an obstacle directly in front of them up to 1.7 meters, which is approximately the length of a cane, through a vibrating motor. The auditory output informs the user if the device has found the object they have specified and its distance from them. For example, the bone conducting headphones will output a statement like "person, x feet left, x feet front." Our hope is to provide a solution that allows visually impaired individuals to feel more confident mapping their environments and maintaining their independence when navigating different types of areas.

In the next sections of this document, we will give a system overview, details of installation of our product, how to use our product, a technical background, and some relevant engineering standards.

2 System Overview and Installation (Author: Annamalai)

2.1 Overview block diagram

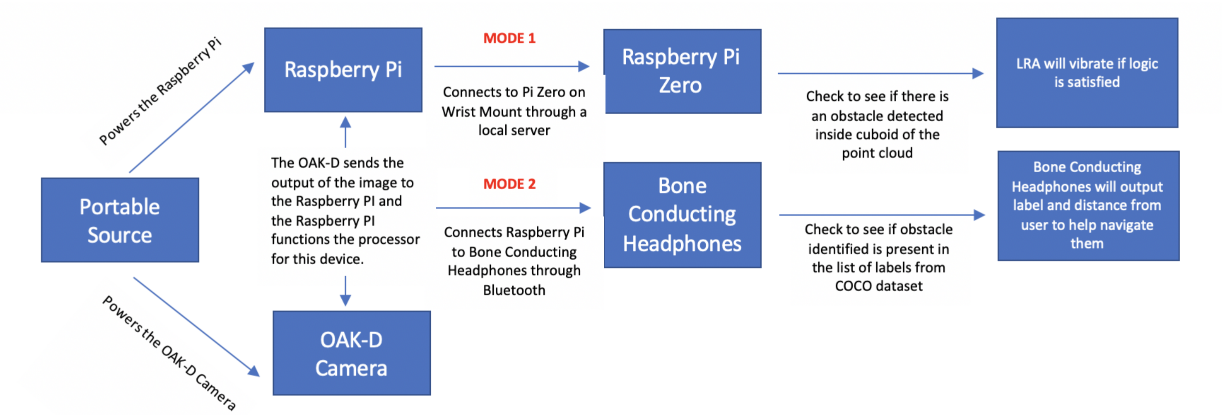

Figure 1.1. System Block Diagram of Opticle

The system begins by powering on using a 5V portable battery source with an output of 3A and capacity of 10400maH. The portable power source is connected to the Raspberry Pi and the OAK-D camera, both of which are interconnected; the OAK-D sends the output of the image to the Raspberry Pi while the Pi functions as the brains and processing power for this device. There is a switch attached to the chest mount controlled by Raspberry Pi as well, which allows the user to switch between the 2 respective modes. Mode 1 will provide the user with haptic feedback after checking if there is any obstacle present within a predetermined region of space. An obstacle is determined by checking the density of points present in the cuboid drawn on the point cloud data. If this condition is satisfied, the LRAs connected to the Pi Zero, which is connected to the main Raspberry Pi through a local server, will vibrate. A depiction of the cuboid drawn in the point cloud data is shown in *Figure 1.2.* If not, the user will know that they can continue moving along the path. Mode 2 is intended for locating certain objects around the user, such as a car for their Uber Ride or a bench if the user is looking to sit down. This will be facilitated through the microphone on the bone-conducting headphones that can listen to the user's requested object upon a prompt from the system. The OAK-D will run through the COCO dataset and check if the object specified is trained on the model and is present in the space. If the object is detected, the bone conducting headphones that are connected to the main Pi via bluetooth will output the name of the label and the relative distance the object is from the user. The LRAs will also vibrate to notify the user of immediate obstacles in a similar fashion to mode 1.

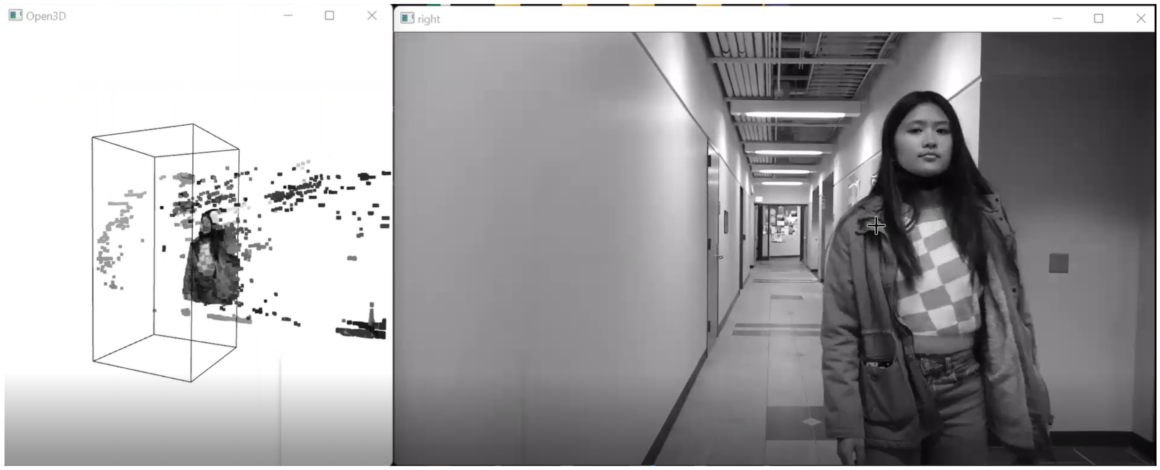

Figure 1.2. Depiction of Cuboid within Point Cloud Data in left window, OAK-D Camera Output in the right window. Obstacle (person) detected is within the cuboid as shown.

2.2 Physical description

Figure 1.3. A user wearing Opticle showing the placement of the components from the back and showing how to wear the wrist mount. On the chest mount, we have a portable battery (left) and a Raspberry Pi 4 (right).

This figure is a depiction of how the user will wear Opticle. There is a portable power source that connects to the Raspberry Pi at the back of the chest mount and the OAK-D camera at the front of the chest mount. The user will also be wearing a wrist mount with a Pi Zero that is connected to the main Pi through a local server and a linear resonant actuator that will provide haptic feedback whenever there is an obstacle detected in the point cloud. When mode 2 is activated, the user will wear bone conducting headphones in addition to the chest mount, and the headphones will output the name of the specified obstacles if encountered and the distance from the obstacle to the user. Below is a diagram of the hardware components in Opticle.

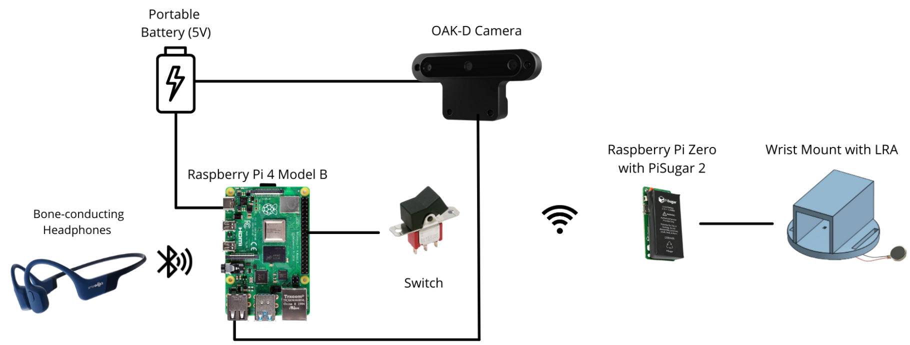

Figure 1.4. This diagram depicts the hardware components and setup of Opticle.

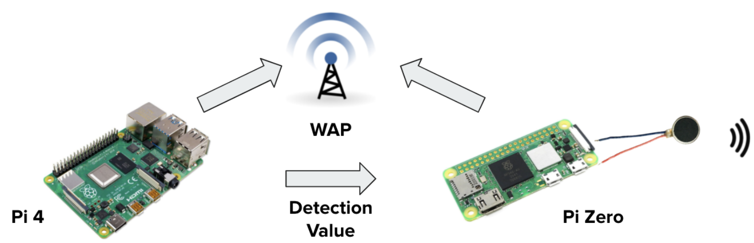

Figure 1.5. This diagram shows how the Raspberry Pi 4 and Raspberry Pi Zero communicate via a wireless access point (WAP). The Pi 4 sends the detection value to the Pi Zero and based on the value, it will indicate whether the motor will vibrate.

2.3 Installation, setup, and support

<u>Raspberry Pi Prerequisites</u>

- Ensure that 64 bit raspberry pi OS is downloaded.
- Ensure that the python3 version is 3.7, this can be achieved with the use of pyenv to set up a virtual environment.
- Access to micro HDMI to access Pi display to run relevant scripts/commands on the terminal.
- Access to the internet through either an ethernet cable or wireless setup by adding the network details to the *wpa_supplicant.conf* file

<u>Setup</u>

- Clone the *https://github.com/amg1998/BUSeniorDesign-Opticle-21-22.git* repository onto both the Raspberry Pi 4 and Raspberry Pi Zero
- *cd* into the *point-cloud-projection* folder on the Pi Zero
- Run the *piserver.py* file on the Pi Zero
- *cd* into the *examples/test* folder on the Pi 4
- Run the *install_requirements.py* file to obtain all the dependencies
- Run the *spatial_tiny_yolo.py* file to detect obstacles within the point cloud/receive audio feedback regarding what the obstacle is
- Turn on the bone-conducting headphones

3 Operation of the Project (Author: Stefan)

3.1 Operating Mode 1: Normal Operation

Physical Setup and System Power On

1. The user will put on the chest mount by putting their arms through the arm loops, making sure the camera is in the front and the portable battery and Raspberry Pi 4 is in the back. Then the user will clip the chest mount together from the back. The straps can be adjusted as needed to fit the user.
2. The user will then strap the wrist mount to their wrist using the velcro straps attached to the mount.
3. The bone conducting headphones can then be put on around the user's head and turned on by a power button on the headphones.
4. When the user is ready to begin, a power button on the portable battery can be pressed to turn on chest mount devices, and a switch on the Raspberry Pi Zero inside the wrist mount can be used to turn on the wrist mount devices.

Mode 1: Vibration

1. Upon boot up, the system defaults to mode 1, which is the vibration only mode.
2. The user will walk around as they usually do while the system is running and looking for potential obstacles.
3. If an obstacle is detected, the motor on the wrist mount will begin vibrating, alerting the user that there is an obstacle in front of them. When the user continues to walk and there is no longer an obstacle in front of them, the motor will stop vibrating.

Mode 2: Audio

1. In this mode, the system will prompt the user for an object that they plan to identify.
2. If the object corresponds to a label in the COCO dataset, the OAK-D will start to scan for the respective label.
3. The user will walk around as they usually do while the system continuously runs and identifies objects in front of them.
4. If an object that matches the user's object they said is identified, the position of the object will be announced to the user via the bone conducting headphones.

Mode Switching

1. In order to change between the two modes on the system, the user can toggle a switch attached to the front shoulder strap on the chest mount.

System Power Off

1. When the user would like to stop using the device, they can power off the wrist mount by using the switch on the side of the Pi Zero. To power the chest mount devices, they can hold down the power button on the portable battery which is located on the back of the chest mount.

3.2 Operating Mode 2: Abnormal Operations

Hardware Errors

1. If the device fails to produce any vibration or auditory output, the portable batteries could be out of power. Another error that could happen particularly if vibration is not working is that the wires to the motor became disconnected. If this were the case, please ask a member of the team to repair the soldering.
2. If the device fails to switch modes, this could be an issue with the wiring from the button to the Pi 4. This would need to be fixed by resoldering the wires together.

Object Identification

1. The system may sometimes misclassify objects detected in the audio mode due to the system assigning it the wrong label. If the accuracy of the device is noticeably incorrect, a team member should be contacted for adjustments and feedback.
2. If the system is no longer reacting to any movement and the user is in an isolated area, the system may have lost connection to Wifi. The user should reenter an indoor environment and reconnect the device to the Internet.
3. If the system cannot understand the object the user said, it will prompt the user to try again. The user can then restate the object they want to look for to the device.

If the user is actively using the device while any errors occur, the user should power off the system first before actively trying to fix any of the issues.

3.3 Safety Issues

1. It is important to remember that this device is meant to act as a supplementary aid for visually impaired people, not as a replacement for their cane.
2. The user should still rely on their cane to catch potential obstacles directly in front of them or any changes in elevation, which the system cannot currently detect.
3. Both Raspberry Pis have a voltage input limit that will prevent them from overheating, so the power source should not be switched out with the current ones provided unless the output remains at 5 volts.
4. Users should be aware of the wires attached around the chest mount so that their body does not become tangled within the device.
5. Users should be careful not to get the electrical components wet as this could cause electrical safety issues. The encasement of electrical components is meant to help protect the device from water, but the device is not waterproof.

4 Technical Background (Author: Luca)

Mode 1 (Point Cloud):

The primary mode of our system is utilized for the detection of obstacles in the immediate path of the user. By determining whether an obstacle is present within a predetermined region of space in front of the user, 1 meter in the x-direction, 2 in the y, and 1.7 in z (assuming the y-direction is orthogonal to the ground, and the z is in the forward direction of motion of the user), our system is able to inform the user of any imminent dangers in their path. Obstacle detection is achieved by determining the density of points that are present within the specified region in the pointcloud that is obtained from the OAK-D.

A point cloud is a set of points in 3-dimensional space that represent a shape or object. In our system, the point cloud is utilized to determine if an obstacle is present because it creates a representation of the space that exists in front of the user given that it contains both rgb and depth data. In order to obtain the point cloud data, the depth and rgb streams from the OAK-D are utilized along with the intrinsic matrix of the camera. The intrinsic matrix of the camera contains information about the camera like focal length, camera center, and skew. Each frame is extracted from the two streams, and a median filter is used on the depth frame to reduce the salt and pepper noise that is present. The intrinsic matrix is needed to map each pixel in the 2-dimensional image to 3-dimensional space.

To determine whether an obstacle is present in the space in front of the user, the number of points that are present within the region of space described above is compared to an established threshold of 5000 points. This threshold was determined by testing the number of points that were present within the region when no obstacles were present. If more than 5000 points are present, then an obstacle is in front of the user.

Mode 2 (Object Detection):

Mode 2 integrates object detection into our system by using the YOLO V4 model with spatial detection in order to determine the position as well as the label of the object that has been detected. The rgb and depth streams from the OAK-D are fed into the model, and an array of detections is returned. The array includes label, confidence and bounding box coordinates. The depthai library has a node specific for YOLO-based models that returns a detection array instead of a byte array that needs to be decoded.

Guidance to Object:

The user would utilize mode 2 through speech recognition. Using Python's speech recognition library, the system will initially prompt the user as the switch is flipped to mode 2 asking " What object would you like to scan for? " The user will then reply using the microphone on the bone conducting headphones. If the label outputted by the user matches a corresponding label on the COCO dataset, the OAK-D will start scanning the surrounding environment. If an object is identified with a confidence level that is above a certain threshold, the position with respect to the user will be outputted through the bone conducting headphones. This would include both the vertical and horizontal distance for eg. “ Bench is 4 meters front and 2 meters left.” The system will continue to provide an updated position of the object if there is a 1.5m change in distance from the object or every 15 seconds depending on which condition is satisfied first. Once the object has been identified and the user has reached the desired position, the user can switch back to mode 1.

Wireless Communication: (Author: Stefan)

The Raspberry Pi 4 on the chest mount and the Raspberry Pi Zero on the wrist mount communicate with each other wirelessly using TCP/IP protocols and socket programming. Both Pis connect to a wireless access point, whether that be a building wifi router or personal hotspot that the user has. The Pi Zero acts as a server and listens for communication over the internet to any devices that connect to the server socket it creates. The Pi 4 acts as a client and creates a client socket that establishes a communication link to the Pi Zero using its IP address and port number and continuously sends messages to it. Whenever the Pi 4 has an obstacle that is detected, a “1” is sent as a message to the Pi Zero, which it receives while constantly listening to the incoming client messages. If there is no obstacle detected, then a “0” is sent as a message to the Pi Zero. If the Pi Zero receives a “1”, it sets the pwm duty cycle of the gpio pin to 100 to make the motor vibrate. If it receives a “0”, it sets the duty cycle to 0 causing the motor to stop vibrating. These responses by the Pi Zero to obstacles being detected happen in near real-time giving the user accurate information on whether there is an obstacle immediately in front of them based on the vibrations felt in the wrist mount.

Pi connections and vibration:

Based on the mode that has been selected by the user (mode 1 or mode 2) either obstacle detection or object detection will be running. If mode 1 is chosen, then the Raspberry Pi 4 will send the status of whether an obstacle is detected to the Pi Zero over the wireless communication. Based on the status that is received, the Pi Zero will either vibrate the LRA motor via a GPIO pin, or do nothing. If the second mode is chosen, then the label of the object that has been detected will be outputted via the bone-conducting headphones.

5 Relevant Engineering Standards (Authors: Jami, Nancy)

Our project consists of multiple hardware components that follow certain engineering standards. Some of the relevant engineering standards for Opticle are listed below:

IIEE 360 Standard for Wearable Consumer Electronic Devices
This standard defines technical requirements and testing methods for different aspects of wearable electronic devices, from basic security and suitableness of wear, to various functional areas. The purpose of this standard is to direct the industry of consumer electronics to provide secure and reliable products to satisfy consumer needs.

ISO 24551:2019 — Ergonomics - Accessible design - Spoken instructions of consumer products
This standard specifies ergonomic requirements and recommendations for consumer product spoken instructions that are provided to guide users in the operation of a product and/or as a means of providing feedback to users about the status/state of a product. Such instructions can be used by persons with or without visual impairments and are useful for users who have difficulty reading and/or cognitive impairments.
(https://www.iso.org/standard/72307.html)

NBSIR 74-606 — Consumer Product Noise: A Basis for Regulations
The Consumer Product Safety Commission is charged with the responsibility for promulgating safety standards to protect the public against unreasonable risks of injury associated with consumer products.There is a risk of injury from noisy products, directly by damage to hearing and indirectly by degradation of essential speech communication.
(https://www.govinfo.gov/content/pkg/GOVPUB-C13-846599e1744a2ab769c13a4b22549e80/pdf/GOVPUB-C13-846599e1744a2ab769c13a4b22549e80.pdf)

Standards Raspberry Pi Zero:
55032:2012 Class B — Electromagnetic compatibility of multimedia equipment - Emission requirements
International standard EN 55032: 2012 applies to multimedia equipment (MME) having a rated r.m.s. AC or DC supply voltage not exceeding 600 V. Equipment within the scope of EN 55013 or EN 55022 and CISPR 13 or CISPR 22 is within the scope of EN 55032: 2012.
Class B - equipment that offers adequate protection to broadcast services in residential environment.

EN55024:2010 — Information technology equipment - Immunity characteristics - Limits and methods of measurement
Defines the immunity test requirements for information technology equipment (ITE, as defined in CISPR 22) in relation to continuous and transient, conducted and radiated disturbances, including electrostatic discharges (ESD)

EN61000-3-2:2014 — Electromagnetic compatibility (EMC) - Part 3-2: Limits

EC 61000-3-2:2014 deals with the limitation of harmonic currents injected into the public supply system. It specifies limits of harmonic components of the input current which may be produced by equipment tested under specified conditions. It is applicable to electrical and electronic equipment having an input current up to and including 16 A per phase, and intended to be connected to public low voltage distribution systems.

EN61000-3-3:2013 — Electromagnetic compatibility (EMC) - Part 3-3: Limits
IEC 61000-3-3:2013 is concerned with the limitation of voltage fluctuations and flicker impressed on the public low-voltage system. It specifies limits of voltage changes which may be produced by an equipment tested under specified conditions and gives guidance on methods of assessment.

6 Cost Breakdown (Author: Nancy)

The cost breakdown below approximates costs to produce one Opticle unit. It accounts for all the hardware and software components of Opticle. All software used was open source; thus, the cost is negligible and not included in the cost breakdown.

The main expenses of the project were the OAK-D camera and the Aftershokz bone conducting headphones. Both of these items were contributed by the client for this project. Our client also supplied the Platinum Extreme Accessory Kit and the Raspberry Pi 4 for this project.

Project Costs for Production of Beta Version				
Item	Quantity	Description	Unit Cost	Extended Cost
1	1	OpenCV AI Kit: OAK- D Camera	$199.00	$199.00
2	1	Platinum Extreme Accessory Kit (Chest Mount)	$29.99	$29.99
3	1	Aftershokz Bone Conducting Headphones	$159.95	$159.95
4	1	Raspberry Pi 4	$45.00	$45.00
5	1	Raspberry Pi Zero	$5.00	$5.00
6	1	Pisugar 2 Portable Battery for Raspberry Pi Zero	$35.99	$35.99
7	1	Charmast Portable Battery Charger	$19.99	$19.99
8	1	Linear Resonant Actuator (Motor)	$3.71	$3.71
9	1	Adjustable Wrist Mount	$8.00	$8.00
Beta Version — Total Cost				$506.63

7 Appendices (Author: Nancy)

7.1 Appendix A - Specifications

The table below outlines the engineering requirements and quantifies the performance of Opticle.

Requirement	Value, range, tolerance, units
Detection accuracy	>95% obstacle detection
Portable Battery	10400 mAh, 5 - 6 volts output
Mode 1: detection range (distance)	1 - 5 meters
Mode 2: detection range (distance)	1.7 meters
Detection range (field of view)	81° DFoV - 68.8° HFoV
Linear resonant actuator response time	<1 second
Audio output response time	<1 second
Device power life	1.5 hours

7.2 Appendix B – Team Information

Team Opticle consists of Annamalai Ganesh, Luca Guidi, Jami Huang, Stefan Wong, and Nancy Zheng. All team members attend Boston University. We chose to create Opticle after seeking out an issue and found that visual impairment impacts millions of people all over the world annually. The whole team is very passionate about the situation and seeks to create a solution that would aid visually impaired individuals. Two of our team members had previously worked with our client, Professor Ohn-Bar, who has been working on projects that were related to the individually impaired. Thus, we decided to pursue this project with our client.

Annamalai Ganesh is a senior studying Computer Engineering with a concentration in Machine Learning. Annamalai will be working as a Software Engineer at Tallan following graduation.

Luca Guidi is a senior studying Computer Engineering and Mechanical Engineering. Luca will be working as a Software Engineer at Expedia following graduation.

Jami Huang is a senior studying Computer Engineering. Jami will be working as a Software Engineer at Publicis Sapient following graduation.

Stefan Wong is a senior studying Computer Engineering with a concentration in Technology Innovation. Stefan will be working as a Product Engineering Consultant at West Monroe following graduation.

Nancy Zheng is a senior studying Computer Engineering. Nancy will be working as a Software Engineer at Microsoft following graduation.

7.3 Appendix C – References

[1] "Vision Loss," *The International Agency for the Prevention of Blindness*, 24-Jun-2021. [Online]. Available: https://www.iapb.org/learn/vision-atlas/. [Accessed: 14-Oct-2021].

[2] National Academies of Sciences, Engineering, and Medicine, Health and Medicine Division, Board on Population Health and Public Health Practice, Committee on Public Health Approaches to Reduce Vision Impairment and Promote Eye Health, Welp A, Woodbury RB, McCoy MA, et al., "The Impact of Vision Loss" in Making Eye Health a Population Health Imperative: Vision for Tomorrow, Washington (DC), USA: NAP, 2016. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK402367/ [Accessed: 15-Oct-2021]

[3] "Canes vs. Walkers - Pros and Cons of Each," *MedPlus*, 18-Dec-2018. [Online]. Available: https://www.medplushealth.ca/blog/canes-vs-walkers-pros-cons-of-each/. [Accessed: 14-Oct-2021].