05/09/22

Dr. Trombetta

Project Sponsor

4722 Calhoun Rd.

Houston, TX, 77074

Dear Dr. Trombetta,

Thank you for expressing interest in the smart cane. This report involves the steps for our project in detail and encapsulates our purpose and intentions for it. A test plan is also utilized to validate the engineering and product specifications. These desired specifications highlight that of the prototype itself rather than the individual components. We have also highlighted in the summary what we have accomplished and setbacks. We also explain what our finalized goals were and how we approached our task of completing a prototype. Overall, the project was a success with takeaways that could possibly help future students in pursuing iterations onto what we did.

Sincerely,

Tuan Nguyen (Leader)

Ryan Le

Kevin Tieu

UNIVERSITY OF HOUSTON
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DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

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TEAM 2
SMART CANE FOR THE BLIND
FINAL REPORT

Leader: Tuan Nguyen
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Kevin Tieu

Table of Contents

Background

The World Health Organization (WHO) estimates 1 billion people in the world have moderate to severe vision with a majority of them being over 50 years old [1]. One obstacle many visually impair people face is navigating safely and independently. The white cane shown in Figure 1, has been widely used to assist them. The user sweeps the cane in front of them to detect any potential hazards. Despite being introduced a century ago, this design remains relatively unchanged and does not detect every hazard. For example, in a survey of over 300 legally blind people, it was reported that head-level collisions occurred twice as often as falls [2]. It is important to dedicate technology and innovation to minimize these dangers and improve the well-being of the user.

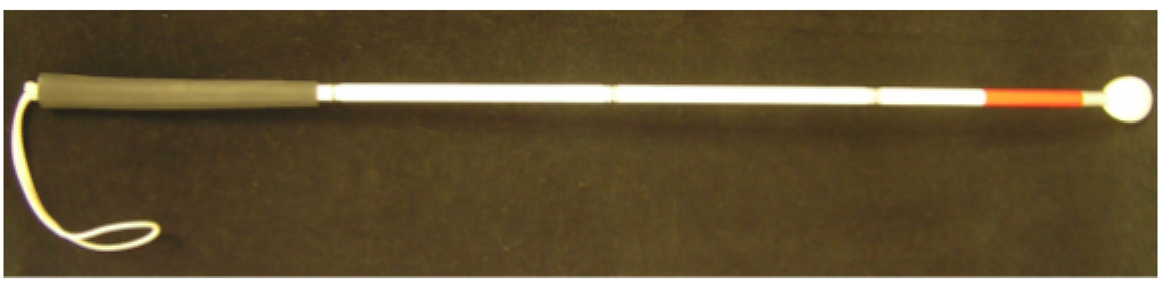

Figure 1. Traditional white cane commonly used by the visually impaired.

Our team is exploring ways to develop a smart cane that will offer better detection than a traditional white cane can. Some attempts at a smart cane use sensors to expand the spatial awareness to detect obstacles beyond the cane and above waist. In addition to sensors, our proposed solution is to use a camera and artificial intelligence. With this, our smart cane can use computer vision to perform object detection. If the smart cane detects a known class like a person, it will announce that to the user through audio. This will inform the user of what is in front of them so they can better visualize their surroundings.

Patents

White Cane with integrated electronic travel aid using 3D TOF sensor

The first patent that seems similar to our smart cane was patent #8,922,759 provisional application #61/386,190 filed on September 24, 2010 titled White Cane with integrated electronic travel aid using 3D TOF sensor. This patent is very similar to our project because we also use a time of flight sensor attached to a white cane to give the user a more active object detection based on distance.

(57) **ABSTRACT**

The invention describes an electronic travel aid (ETA) for blind and visually impaired persons implemented in a detachable handle of a white cane. The device enhances the functionality of the white cane giving the user more detailed information about the environment within a defined corridor of interest in front of the user with an extended range of a few meters up to 10 m. It provides a reliable warning if there is a risk of collision with obstacles including those at trunk or head height, which are not recognized by a conventional white cane. Additional sensors are integrated to delimit the defined corridor during the cane sweeping thereby reducing the amount of information that is transmitted to the user via the tactile interface. Alternatively, the device can be used independently from the cane as an object recognition and orientation aid.

Figure 2: Abstract of patent #8,922,759

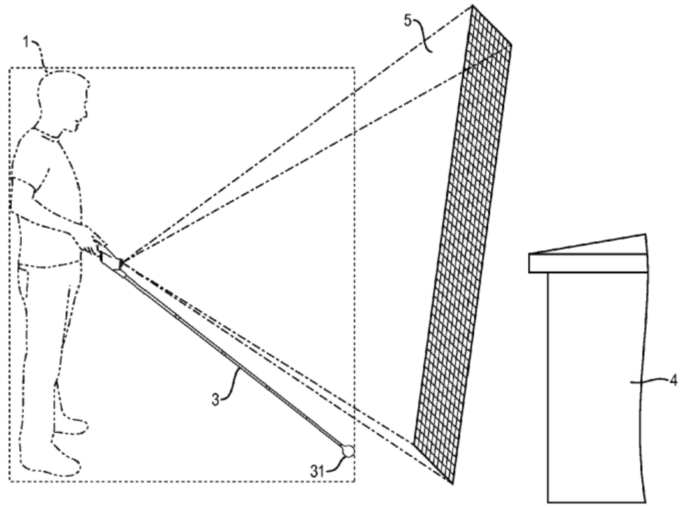

Figure 3: The design of patent #8,922,759

Navigation Device for Use by the Visually Impaired

Second patent relating to our smart cane was patent #6,774,788 provisional application #10/226,201 filed on October 07, 2002 titled Navigation Device for Use by the Visually Impaired. Although this device isn't attached onto a cane, it is still handheld and uses object detection through camera and relaying feedback through audio. This is similar to our smart cane because we interfaced a camera with machine learning to deploy our object detection and are currently in the midst of implementing audio feedback. It differentiates from our smart cane by including a Braille display, which is useful in noisy environments where the use of headphones is ineffective. Another feature is the use of a wireless finder, which is used to locate the device when it is accidentally dropped.

(57) **ABSTRACT**

A handheld navigation device for use by the visually impaired having a camera electrically connected to a microprocessor. The microprocessor is capable of object and character recognition and translation into Braille. A Braille display is electrically connected to the microprocessor. A speaker is electrically connected to the microprocessor for audibly communicating common objects and distances and character recognition translations to the user.

Figure 4: Abstract of patent #6,774,788

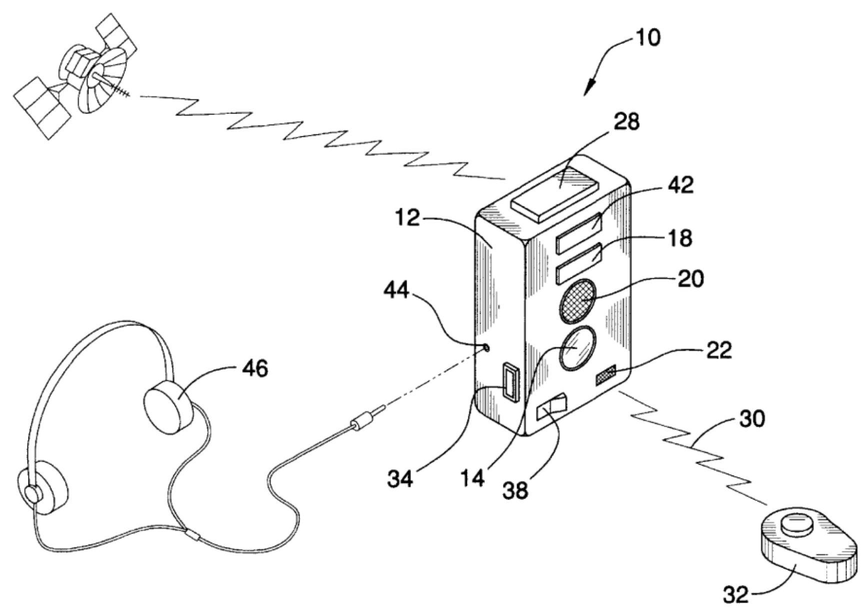

Figure 5: Overview design of patent #6,774,788

Overview Diagram

Figure 6 outlines our overview diagram with included components for the smart cane. A camera module will be used to identify obstacles when interfaced with machine learning. Distance sensors will be interfaced with haptic motors and a speaker to notify when an object is at certain distances ie. 4 meters say “person detected”. A multiplexer will be used to allow multiple I2C modules to be operated in tandem. The raspberry pi will be our processor to allow interfacing and implementation of machine learning and components together. For portability, a battery pack is utilized for roaming around with the cane.

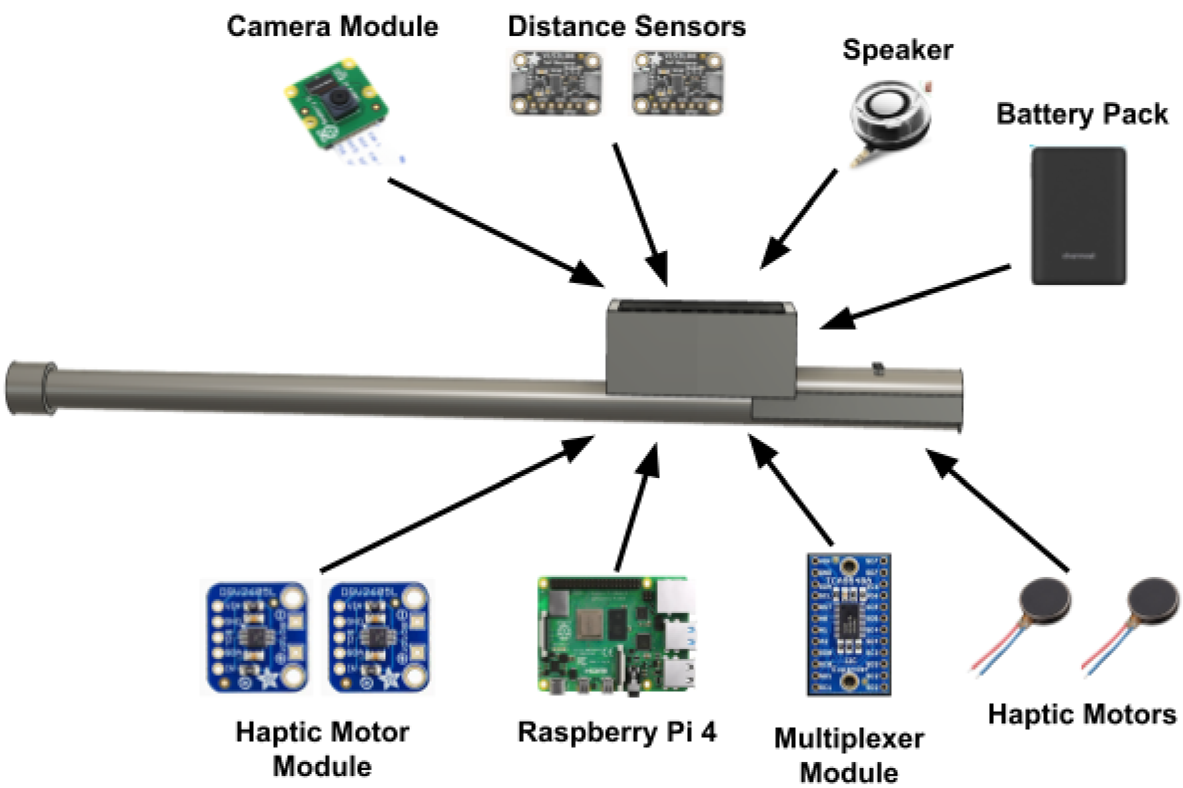

Figure 6: Smart Cane Overview Design

Deliverables

Our smart cane will have a target weight of 1 lb without the power supply. It will also have a target battery life between 6 and 8 hours and will recharge using a USB Type C connection. Our smart cane will have an integrated camera designed to perform object identification using machine learning. We will also equip it with distance sensors to detect obstacles within 4 meters. This information will be relayed to the user through haptic feedback and audio notification.

A test plan table for each task is given below. Each task is labeled with functionality such as a battery or speaker interfacing. From there, testing parameters are established to have a quantifiable spec that could be measurable and verified. For target values of each task, it is set to accommodate the specifications of the prototype in relation to a specific competitor specification, the WeWalk. Furthermore, these are desired values found to be close to that of the WeWalk, and the goal is to obtain these desired values using the set testing parameters and verification methods for each task.

Table 1: Test Plan

Task #	Functionality	Testing Parameters	Verification Method	Target Values
1.4	Battery	Charging time, Battery life,	Record draining time under full workload and charging time from 0 to 100%.	Draining time: 6-8 hours Charging time: less than 7 hours

2.1	Distance Sensor Interface	Accuracy, range	Test the sensor reading under various lighting conditions (dark,, sunny, normal lighting), target's color (white, gray, black) and target's surfaces (reflective, smooth, rough)	Accuracy: ± 4 [cm] Range: effective within 2 meters in worst condition FOV: 20 degrees
3.2	Object Detection	Class, Distance, Night	Verify objects at various distances, lighting conditions and environments	Detection class: People, Cars, Unidentified Range: Up to 4 meters

Specifications

We have listed our target specs in the bulleted listing below. The first being weight, which is an important spec to consider. Since the user has to travel while holding the cane leveled, it is critical that the cane be light enough to allow comfortability and longer usage. Our next consideration was the battery life. Since the cane would be used to navigate surroundings on a daily basis, a target of 6-8 hours of battery life seems appropriate. For example, it would allow the user to navigate through a grocery store or a shopping center without having the battery run out too soon. Our next spec is an integrated camera. This camera is interfaced with the speaker so when a known obstacle is detected, the speakers will output the name of it ie. humans or cars. The target for obstacle detection distance is 4 meters to allow the cane to process the obstacle and relay to the user in a timely manner. Finally, a power input of USB type c would allow for fast charging of the cane for the user to resume activities after a short charge if they forgot to replenish the battery after usage.

- Target Weight: 1 lb. (without power supply)
- Target Battery Life: 6-8 hours
- Integrated Camera: Yes
- Target Obstacle Detection Distance: 4 meters
- Power Input: USB Type C

The cane utilizes LiDAR sensors to detect obstacles ahead up to 4 meters precisely and the field of view is 20 degrees. A multiplexer is added to allow interfacing of multiple I2C modules simultaneously. With that in mind, the purpose serves in using two vibration and LiDAR sensor modules to distinguish left and right respectively with capability of interfacing up to eight I2C modules. The battery pack is 10000 mAh, 5V DC, and 2A which is sufficient for supplying power to the Raspberry Pi 4, our chosen processor, which lists that exact input voltage and input current. With that in mind, our smart cane managed to last 6 to 8 hours when left to drain in full operation when testing. Our camera when paired with the machine learning managed to update continuously at 2-4 frames per second. The machine learning obstacle identification managed to obtain 60-80% validation confidence or accuracy when identifying obstacles.

Flowchart

Listed below is the flowchart with the corresponding task numbers. The camera feed (Task 2.3) will gather information visually for the object detection (Task 3.2) which is our machine learning. From there, if an object is identified, there will be audio feedback (Task 2.4) to state what object it's detecting via “person detected” or “chair detected”. There will also be vibration feedback (Task 2.2) contingent upon the obstacle being less than 2 meters based on the distance sensor reading (Task 2.1) and it being identified by the object detection. If the obstacle is less than one meter, the audio feedback (Task 2.4) will output that it is close so “person close” or “chair close”.

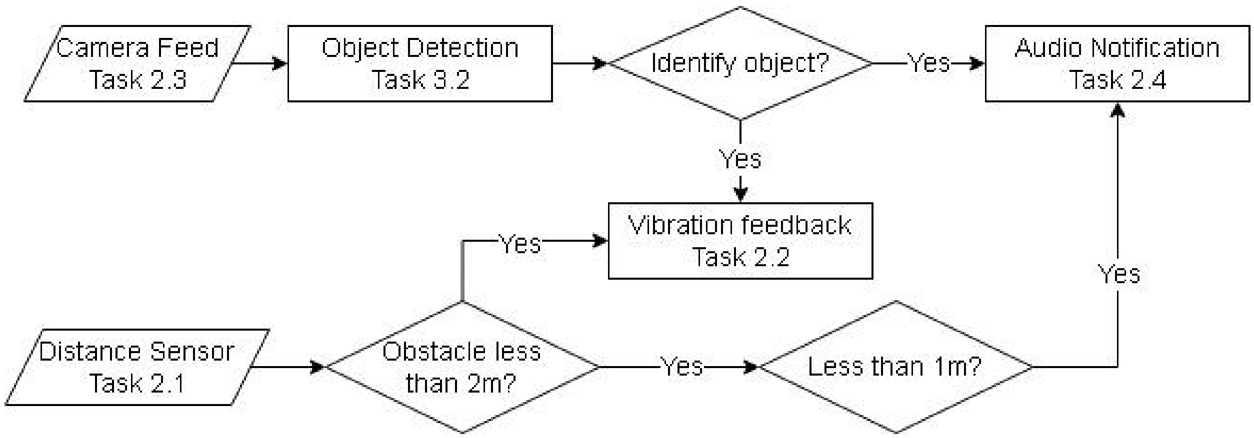

Figure 7: Tasks Flowchart

Risk Management

Table 3 shows a risk matrix and mitigation plan for the project. Interfacing two distance sensors properly is the highest risk for the project. We are in the process of determining whether or not our processor can handle and read at least two distance sensors. This task is very crucial because it is interfaced with the haptic motors. Since these haptic motors vibrate left, right, or center to indicate direction and distance of the obstacle, it is important that the distance sensors operate properly to give the cane a sense of direction of the perceived obstacle. Our next risk is interfacing the speaker and machine learning together. The camera paired with machine learning can identify certain obstacles, but needs proper feedback to the user. This is where the speaker is introduced. The speaker will allow the user to hear the feedback of what the camera and machine learning detected such as a human ahead. The next risk to consider is from object detection. It should be able to detect in most cases and rarely fail to identify the obstacle properly. Battery installation is also a risk worth considering. Since we added more components to the cane, it is important to test and monitor the drain time from full to empty of the battery to see if it will suffice for daily usage. Our final risk consideration is the 3D printed enclosure. The concern with the enclosure is if it'll print properly to give us appropriate dimensions for a good fit of the components and onto the cane.

Table 2: Risk Matrix

Risk Matrix		**Severity**				
		Insignificant 1	Minor 2	Moderate 3	Major 4	Severe 5
Likelihood	Almost Certain 5					
	Likely 4		Task 1.1		Task 2.1	
	Possible 3			Task 3.2 Task 1.3	Task 2.4	
	Unlikely 2					
	Rare 1					

Table 3: Mitigation Plan

Task	2.4 Speaker Interface	2.1 Distance Sensor Interface	3.2 Object Detection	1.3 Battery Installation	1.1 3D Print Enclosure

Mitigation Plan	Test speaker before implementing code for obstacle identification audio feedback	Implement two additional sensors to detect left and right direction as well as record data of sensor readings at different angles	Monitor and record accuracy readings for each object identified	Test with all components assembled and monitor drain time to ensure target spec range is met	Design simple enclosure for ease of 3D printing to prevent failed prints.

Final Schedule

The tasks table coincides with the GANTT chart shown below. As it stands, this is the committed schedule. Each task involves subtasks. As these subtasks are achieved, a percent of the overall task will be satisfied. Looking at the tasks table, we see that the percent completed for hardware implementation, software interface, and machine learning to be 100% across each task. These percentages are based on cumulative percentages of the subtasks. Furthermore, our deliverables and completion of tasks were successful as we were able to complete and deploy a prototype for demo. The vision we set out for the cane originally set in our GANTT chart were delayed due to setbacks pertaining to problems with the 3D printer (Task 1.1) for example which delayed printing of the enclosure by two weeks. Other setbacks were interfacing two distance and two vibration modules at the same time and finding the proper speaker since the Raspberry Pi 4 did not have a dedicated I2S pin for sound. Overall, the project is completed and Figure 10 encapsulates the schedule and completion of it.

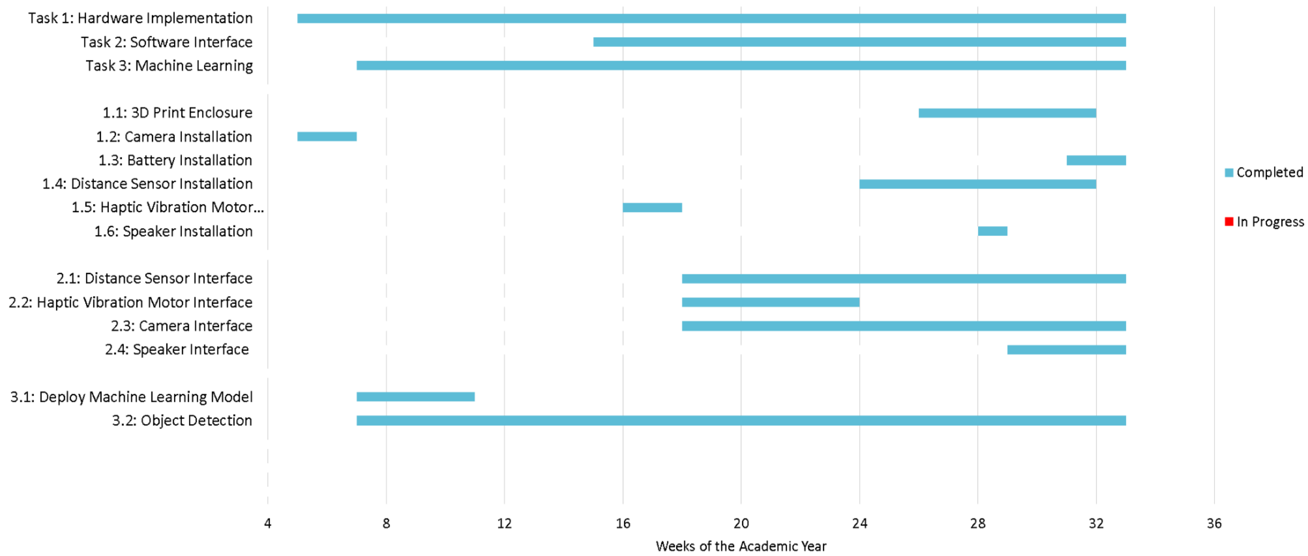

Figure 8: GANTT Chart

Accomplishments

We were mostly successful in completing our deliverables for our smart cane. We deployed a pre-trained object detection model to have the smart cane identify certain objects that could benefit the user. Speakers were used to output the classes detected by the model. We incorporated two distance sensors to gather information about obstacles within two meters. They were mounted with a 20 degree offset on the left and right to help distinguish left and right obstacles. With the addition of a multiplexer, the two sensors can communicate to the two haptic motors located on either side of the handle. These will vibrate with varying intensity to notify the user of any close obstacles either on the left or right side.

After we built our prototype, we tested our smart cane and we were satisfied with our results. Considering that we are using a Raspberry Pi, there's only so much performance that we can extract for our machine learning. Having only 2 to 4 frame per second (FPS) of real time object detection is not ideal but we were still more than happy with the results. Our smart cane is able to detect and announce the class it is detecting. With the help of the distance sensors, it can tell whether that class is close or not. We tested our smart cane around the engineering building and it was able to detect the students walking by most of the time.

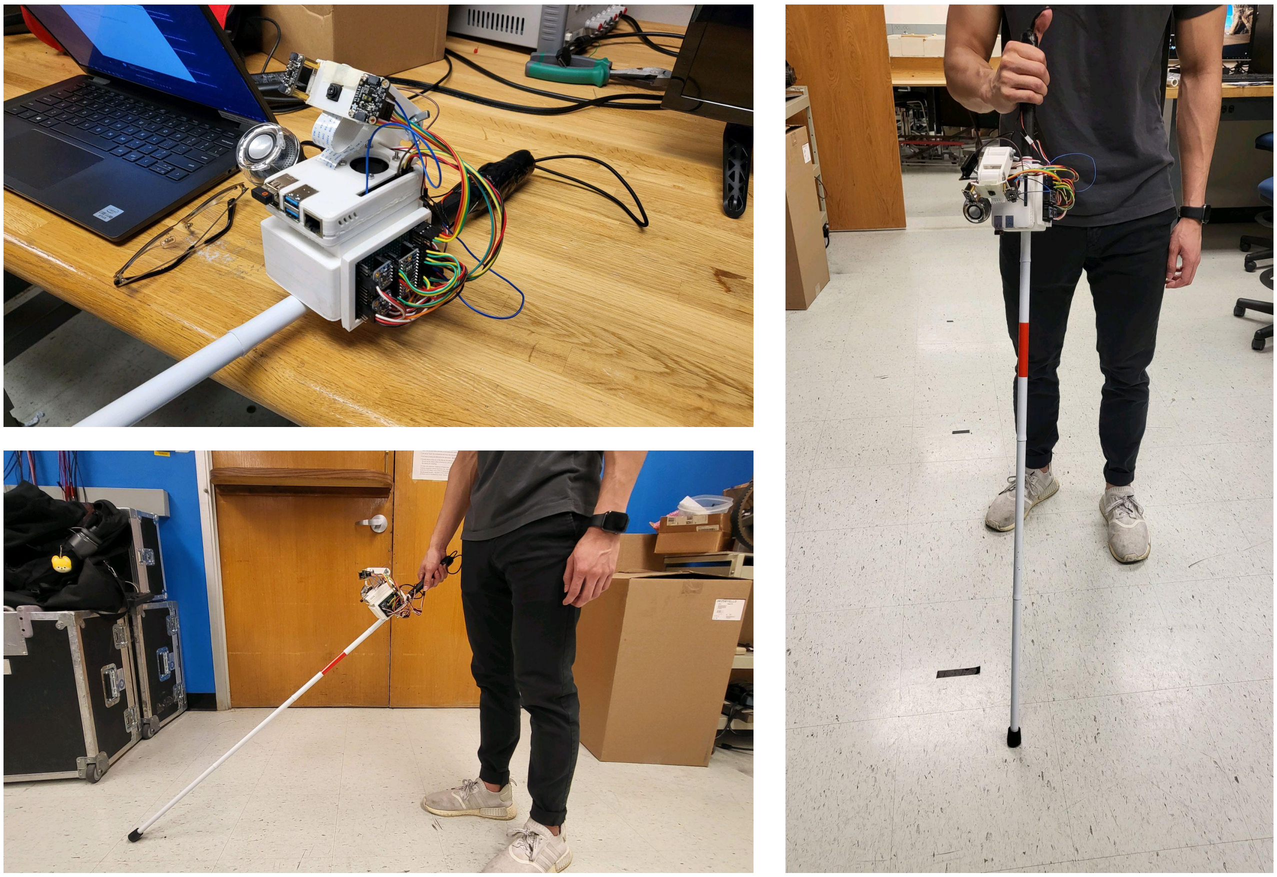

Figure 9: Physical Prototype

Our demo shows our smart detecting the three classes: person, chair and car. First, the user is walking down a hallway and detects a chair followed by a person. The user does multiple laps through the hallway. Then, the user is outside, walking towards a car where we encounter an issue. One oversight we failed to see was that the sunlight interfered with the readings of our distance sensors. Our smart cane would consistently say an obstacle was close despite nothing being there.

[Team2_Smart_Cane_Demo.mp4]

Setbacks

Over the past semester, we encountered several setbacks that we were able to find solutions for. The first setback we encountered was trying to use two distance sensors to communicate with the two haptic motors. Since the Raspberry Pi has only one I2C channel, we had to change the default I2C address for one of the distance sensors. Also, The haptic motors' default I2C address cannot be changed manually, we had to purchase an I2C multiplexer to control the haptic motors separately. This allowed both sensors to communicate with the left and right haptic motors to provide the general direction and proximity of the obstacles.

Another setback was outputting the classes of our object detection model as speech. Our initial attempts would drop the performance of our object detection from 4.5 FPS to less than 1 FPS. A solution we came up with was using a speech to sound conversion to create MP3 files of what the cane will say. For example, if the cane detects a person, the MP3 file will say "Person detected" if they are within 3.5 meters or "Person close" if they are less than 2 meters from the sensors. We also delayed the time between each speech output to a 2 seconds to prevent the Raspberry Pi from trying to repeat it constantly. These implementations allowed the object detection to only drop to 2 FPS now. Last, there was the setback mentioned previously about the sunlight interfering with our distance sensors outside. This caused the distance sensors to send false readings, making speaker constantly said an obstacle was close which defeats the purpose of using this to navigate outside.

3D printing the enclosure proved challenging. After designing the enclosure to house our components, we anticipated multiple prints to find the proper dimension and fitting. However, the 3D printer broke down and had to be troubleshooted and fixed which delayed the completion of it (Task 1.1) by two weeks.

There are still improvements that need to be made. We need to optimize the vibration patterns to better notify the user. There is also a need to find ways to better use object detection with the distance sensors For example, based on how we programmed our smart cane, if the cane detects a person a few meters in front of them but the distance sensor is receiving data from a nearby obstacle like an adjacent wall, it will think the person is close to the user and say “Person close”. Finally, there is the issue of hardware limitations but an easy fix is to purchase a more powerful but more expensive processor like the Nvidia Jetson Nano that is designed to run artificial intelligence.

Summary

While we were able to build a working prototype, the past year brought along a host of challenges for us to overcome. This was my team’s first attempt at an ambitious version of a smart cane. We explored working with a Raspberry Pi microprocessor and learned a new language, Python. We got exposure to artificial intelligence and computer vision. We developed some CAD skills to 3D print most of our parts. All of these allowed us to further develop our problem-solving skills which is the core part of any engineer. We had encountered several problems and setbacks that required us to think outside the box or look for alternative methods.

This past semester, we incorporated some project management aspects like the Gantt chart and risk management. We quickly realized how useful these are and believed this should have been done in the previous semester, specifically the Gantt chart. We could have an overview of our project tasks and which would allow us to better manage our time. There were some tasks that we could have started in the previous semester but we did not have a clear overview of how everything was interconnected.

For future work, we would have liked to experiment more with our object detection using OpenCV library. However, that would work best with a more powerful processor to fully benefit from the real-time object detection. A processor like the Nvidia Jetson Nano would be able to output 20 fps when running the pre-trained model that we have. In addition, we

Regardless, we are proud to deliver a working prototype and have a demo showcasing our hard work. While our prototype is far from perfect, we're happy to see our vision at the beginning of the year come into fruition.

References

[1] World Health Organization. (n.d.). *Vision impairment and blindness*. World Health Organization. Retrieved September 19, 2021, from https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment.

[2] Manduchi, R., & Kurniawan, S. (2010). Watch Your Head, Mind Your Step: Mobility-Related Accidents Experienced by People with Visual Impairment, Tech. Rep. UCSC-SOE-10-24, University of California, Santa Cruz.

Appendix

Guide that we used for the basis of our object detection

GitHub - EdjeElectronics/TensorFlow-Lite-Object-Detection-on-Android-and-Raspberry-Pi

Haptic Controller Module Datasheet

https://cdn-learn.adafruit.com/downloads/pdf/adafruit-drv2605-haptic-controller-breakout.pdf

Multiplexer Module Datasheet

https://cdn-shop.adafruit.com/datasheets/tca9548a.pdf

Time of Flight Sensor Datasheet

https://www.digikey.com/en/products/detail/stmicroelectronics/VL53L1CXV0FY-1/8258055