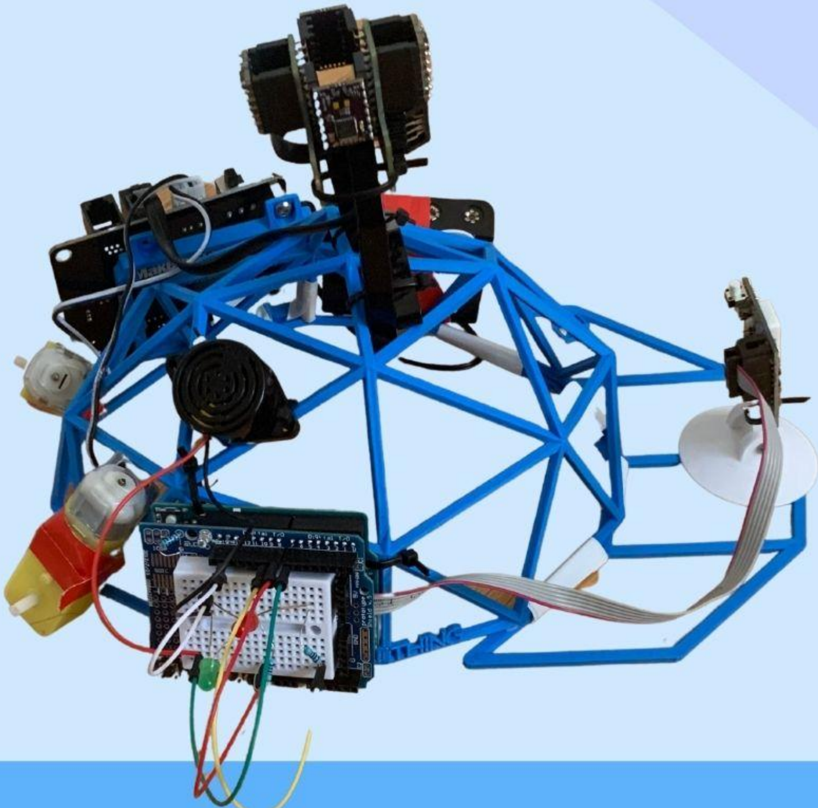
CAT-EYE
(Covid Alert Technology)

An AI and IoT-based COVID-19 Alert Technology for the Visually Impaired

Saurav Gandhi - Project E48 - 11th grade

Not an RRI Project



Problem Statement

The World Health Organization (WHO) estimates that in 2012 there were 285 million visually impaired people in the world, of which 246 million have low vision and 39 million were blind. That means 3% of the world's population is visually impaired in some form or the other. Globally, the entire world is on edge because of COVID-19, and social distance and wearing a mask has become a new normal to prevent its spread. However, visually impaired people are finding it hard to maintain their independence in the new social distancing guidelines.

Problem 1

Visually impaired people are unable to utilize typical solutions such as white cane or dogs to maintain social distances and as a result are assumed to face increased barriers in numerous domains of their lives.

Problem 2

Visually impaired people are more vulnerable to the COVID-19 infection since they cannot tell if someone in their close proximity are wearing a mask or not.

Problem 3

Social distancing guidelines published by CDC are even difficult for the normal population and it appears that the visually impaired segment of the population have been ignored as part of this solution. For visually challenged people, it is difficult to easily confirm if they are keeping the social distance with people around them.

How can the visually impaired observe social distancing guidelines while still verifying that those close to them are wearing masks, without additional dependency on people around them?

Engineering Goal

The goal of this project is to improve mobility and quality of life of visually impaired individuals by developing an alert system that helps them maintain social distance with others and detect if those in proximity are wearing a mask.

Background Research

Research Paper - Impact of COVID-19 pandemic on people living with visual disability **Key Takeaway**: Individuals living with visual impairments are more likely to be affected by COVID-19 than their peers without such impairments. This means that more than 253 million people worldwide will be at greater risk of becoming infected. An unprecedented pandemic, followed by a nationwide lockdown, is a direct threat to the people living with visual impairments and will even endanger their lives in the long run.	**Online Article - Top Resources for the Blind During COVID-19** The resources listed are tips & ideas, details about peer support groups, apps, etc., for the blind and low vision community. **Online Article - Social distancing has left the visually impaired particularly isolated – it's time to reach out** Visually impaired people already experience loneliness at higher levels than the general population. Also, they're more likely to suffer from depression and have more detrimental health outcomes because of self-isolation. **Online Article - Microsoft Corporation: Custom Vision documentation** **Key Takeaway:** Microsoft Azure Custom Vision Website resources
Research Paper - Building Resilience against COVID-19 Pandemic Using Artificial Intelligence, Machine Learning, and IoT: A Survey of Recent Progress **Key Takeaway**: Many medical sector applications such as drug delivery and infection detection based on AI and ML have been presented in this paper, and AI and ML applications for forecasting disease trends and developing social awareness programs. Also, the potential applications of wearables to track and report patients infected with COVID-19 and the recent advancements in IoT have been reviewed.	
Research Paper - Color quotient based mask detection **Key Takeaway:** The paper focuses on mask detection in the age of COVID – 19. The approach includes a feature extraction step, followed by a supervised learning model built with support vector machines. The ratio of color channels is taken into account to distinguish between the mask and non-mask images.	**Social Media: @RNIB (Royal National Institute of Blind People):** Video showing challenges faced by blind people during COVID **Social Media: #AskDontGrab** How can you best help someone with visual impairment during lockdown? #AskDontGrab, as blind Twitter users emphasize, give people distance if you think they're struggling to see you. Don't shout at people who accidentally encroach on your space. Announce who you are, and tell people when you're leaving so they don't end up speaking into thin air.
Research Paper - Remote Assistance for Blind Users in Daily Life: A Survey about Be My Eyes **Key Takeaway:** The app Be My Eyes pairs blind users, with sighted volunteers for a video and audio connection. It has a large number of sighted and blind users.	

Design

Design Criteria

1. The device should be designed using CAD and manufactured with a 3D printer for maximizing adaptability and affordability.
2. Audio/Vibro-Tactile/Sensory feedback should be used to communicate information to user.
3. The device should output feedback to indicate the presence of people within six feet of proximity.
4. The device should use computer vision/AI/IoT to alert the user of maskless individuals in proximity
5. The device should have the ability to communicate to others that the user is blind.

Design Constraints

1. CAT-Eye should be a wearable (i.e. cap, necklace, fanny pack) to allow the assistive technology to "blend in" with every day apparel.
2. The scope of mask detection will be limited to the scope of the AI Image Recognition Library.
3. The range of detection is limited by the scope of the LIDAR Sensor (2 meters).
4. The range of detection is also limited to the specific computer vision camera's range.

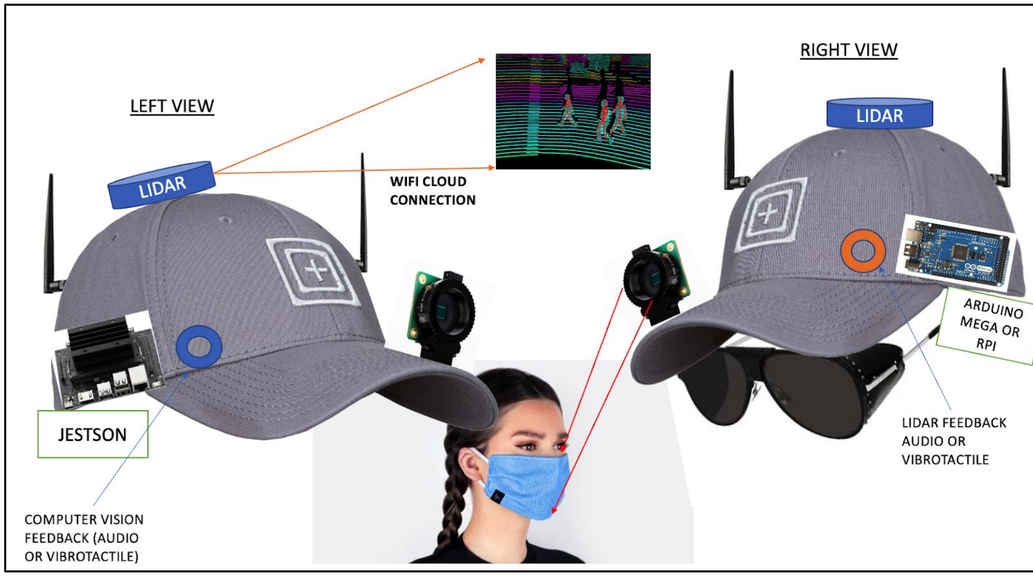
Subsystem Design

Based on the identified Criteria and Constraints, the following three subsystems of the CAT-Eye were identified:

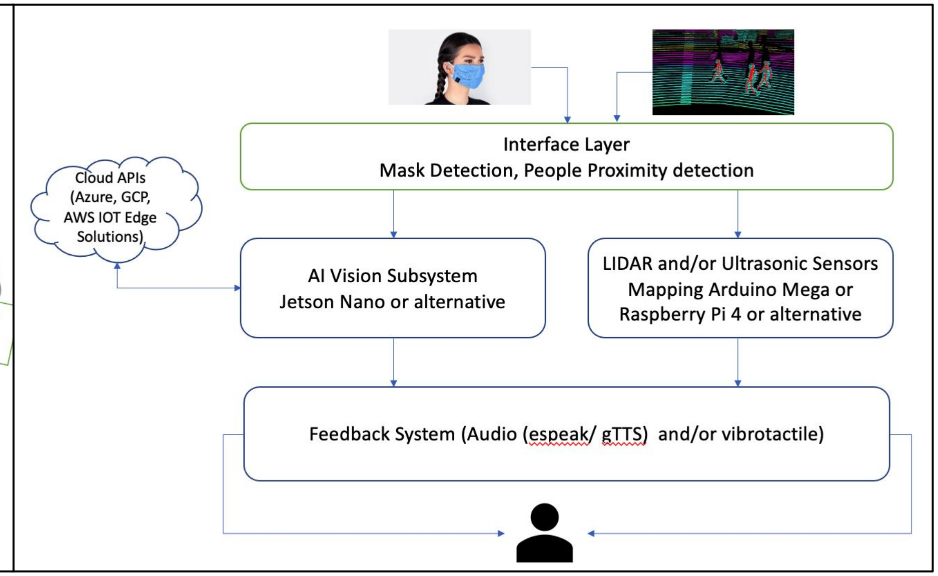
	Proximity Sensing	Mask Detection	Public Alert
Objective	When individuals come within six feet of the user, CAT-EYE notifies the user of their presence and general location through vibrotactile motors.	When individuals within six feet of the user are not wearing a mask, the device beeps to warn the user.	When the user is in area with a larger population, the user can make their device emit a soft audio alert, notifying people in their immediate surroundings of their presence.
Potential Hardware Tools	LIDAR sensor, Arduino UNO, Cameras, Vibration Motors	Jeston Nano, Arduino UNO	Raspberry Pi, Arduino UNO, Speaker
Potential Software Tools	Arduino C++, Python	Azure IoT Edge, TensorFlow, PixyMon, Arduino C++	Raspbian, Arduino C++

Initial Design

After conducting extensive research on different wearable devices for the visually impaired, it was decided that a cap would provide the best position for a field of vision and have the structural ability to store the three proposed subsystems (Proximity Sensing, Mask Detection, Public Alert).



Initial Design System Architecture



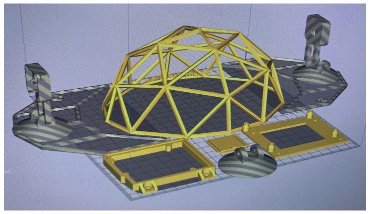
Initial Design Logic

Prototypes

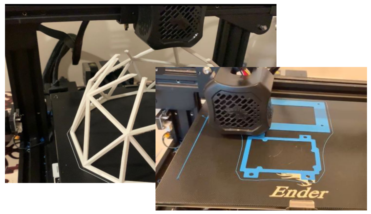
	Proximity Sensing	Mask Detection	Comments
Prototype 1A	MappyDot Plus LIDAR + VibroTactile Motors	Pixy Cam 2 + Arduino	Pixy Cam 2 relied on the color of the masks, so only surgical masks were supported.
Prototype 1B	Same as Prototype 1	Raspberry Pi Cam + Raspberry Pi 4	Raspberry Pi was freezing during execution and was unable to run the model.
Prototype 2A	Same as Prototype 1	Raspberry Pi Cam + Jetson Nano 2G with Azure Custom Vision & TensorFlow	Mask detection did not work for people behind the user. Jetson Nano 2G only had two camera ports.
Prototype 2B (In development)	Two cameras (front and back of cap)	Raspberry Pi Cam + Jetson Nano 4G with Azure Custom Vision & TensorFlow	

Build Procedure

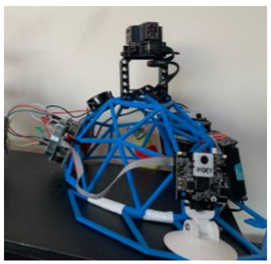
Step 1: Design



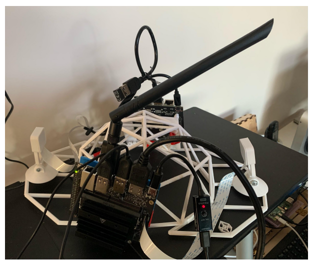
Step 2: 3D Print



Step 3: Build



Step 4: Improve

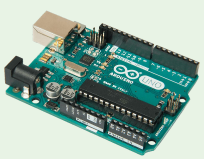


This procedure outlines the process for constructing the baseline prototype hat which acted as a structure for both prototypes.

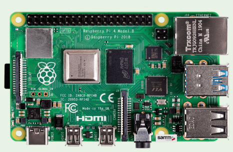
- Design Base Chassis using CAD software (Modified from template on Thingiverse)
- Ensure that the hat is designed to fit all desired microcontrollers, components, and cameras
- 3D print designed hat using the Ender 3 3D Printer
- Mount RaspBerry Pi/Arduino/Jetson to the 3D printed hat
- Mount a camera to the front (and back if applicable)
- Secure LIDAR to the top of the hat
- Program all components using Arduino C++ and Jupyter Notebook
- Tweak parameters on mask detection/camera algorithm
- Continue to test and improve upon the recognition abilities of the device
- Refer to Prototype specs for the prototype-specific procedure

Tools & Services Mapped to Prototype

Microcontrollers



Arduino UNO
(Prototype 1A)

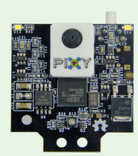


Raspberry Pi 4
(Prototype 1B)

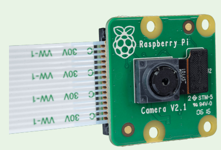
Jetson Nano 2G
(Prototype 2A)

Jetson Nano 3G
(Prototype 2B)

Cameras



Pixy Camera 2
(Prototype 1A)



Pi Camera
(Prototype 1B, 2A, 2B)

AI Tools

Pixymon
(Prototype 1A)

Azure Custom Vision, TensorFlow, Open CV
(Prototype 1B, 2A, 2B)

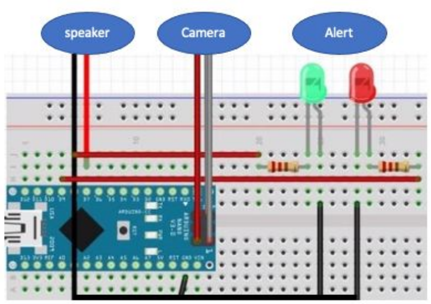
Programming Tools

Arduino C++
(Prototype 1A)

Python, Jupyter Notebook
(Prototype 1B, 2A, 2B)

Prototype 1A	Goal: Leverage Mappy Dot LIDAR, Pixy Cam 2, and Arduino UNO to build a baseline, proof-of-concept.

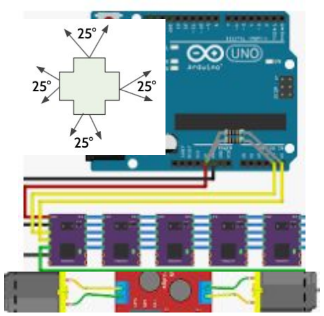
Mask Detection Subsystem



Mask Detection System Architecture

The cmuCam5 (Pixy Cam 2) uses computer vision and the color of objects to create "signatures" for specific items like a mask. When a person is detected who is not wearing a mask, the device flashes red and beeps out loud.

Proximity Sensing Subsystem



Lidar feedback Subsystem

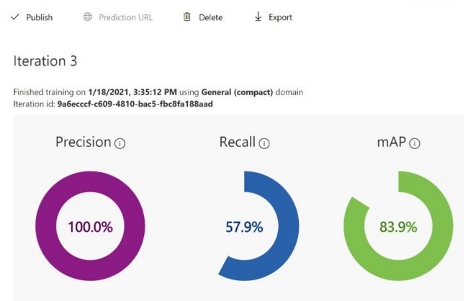
The Mappy Dot LIDAR uses lasers to provide distance measurements up to 2 meters in all four directions, which is a vast improvement over an ultrasonic sensor. The LIDAR drives the DC Motors connected to the Arduino to communicate the general direction of an approaching individual within 6 feet.

Learnings/Comments

This prototype had an overall 71% success rate (more details in testing section). The device functioned fairly well, however, it could only detect surgical masks.

Prototype 1B	Goal: Leverage AI & IoT Tools to create a more versatile mask detection system that will go beyond surgical masks.

Mask Detection Subsystem



Training model on Custom Vision AI

In order to expand mask detection capabilities, a custom image recognition model was trained using Azure Custom Vision. The model was trained three times to maximize effectiveness and downloaded as a TensorFlow Lite algorithm.

We were able to achieve overall accuracy of 83.9% on our data set of 85 images with 3 iterations. OpenCV was then installed on the Raspberry Pi to run the TensorFlow Algorithm. Once the algorithm was successfully installed on the Raspberry Pi, Python was used to program the audio output.

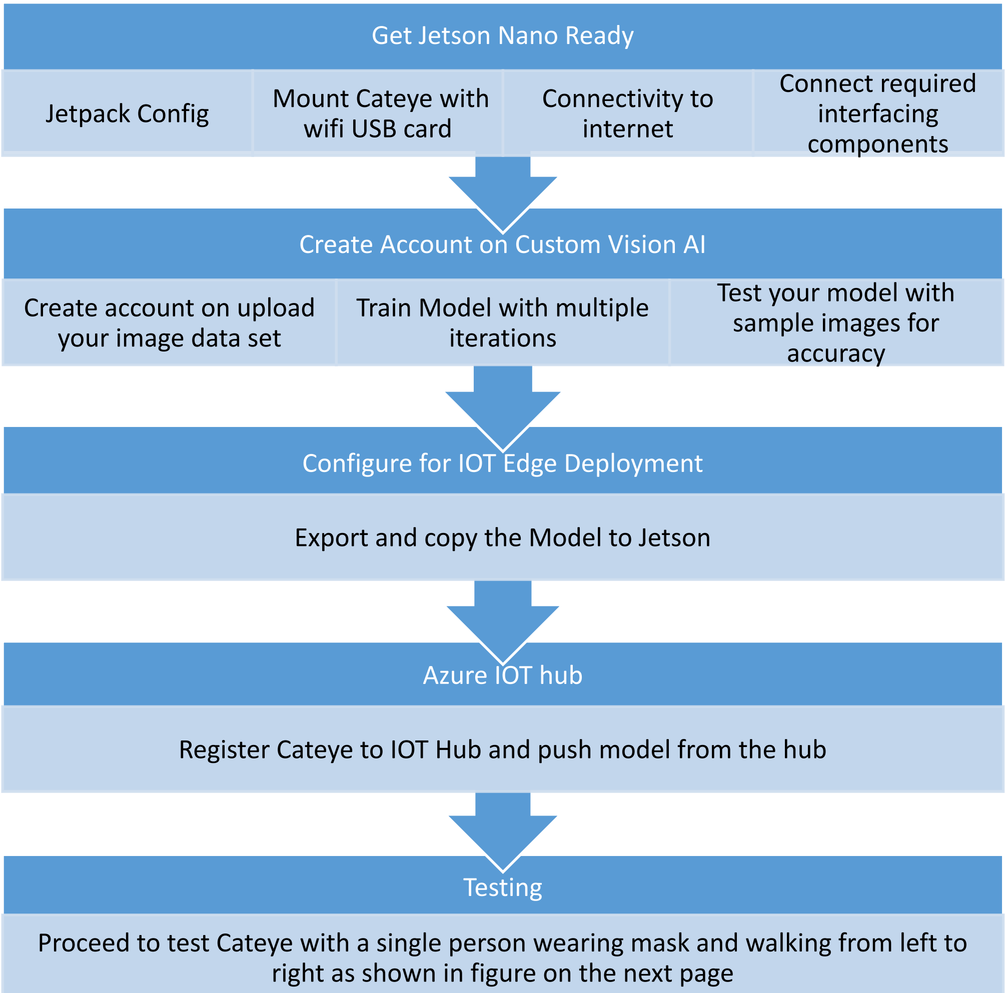
Proximity Sensing Subsystem

No changes were made to the proximity sensing subsystem.

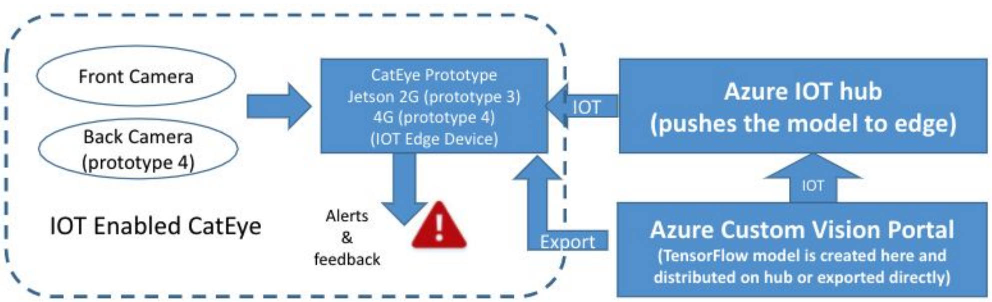
Learnings/Comments

This prototype was largely *unsuccessful* because the Raspberry Pi was unable to run the TensorFlow Lite model due to processing power problems. Due to low functionality, testing *was not* conducted. As a result, another microcontroller was required to fulfill the prototype 1A goal.

**Please note that the public alert system was not included in iteration specs due to the simplicity of the system (speaker with button)*



CATEYE Jetson Nano Development Process



Jetson Nano IoT Architecture

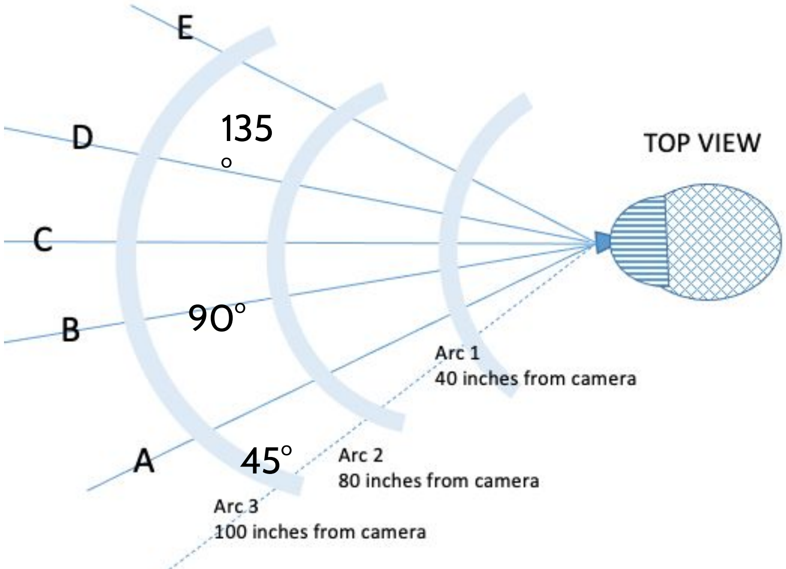
Prototype 2A	Goal: Leverage NVIDIA Jetson Nano to fulfill Prototype 1A Goal. *Note: This device is referred to as Prototype 2 because a new hat was constructed to accommodate a larger board*

Mask Detection Subsystem
The NVIDIA Jetson Nano was able to handle the TensorFlow model and execute the program. The NVIDIA JetPack SDK was leveraged to install and configure the algorithm. It bundles all the Jetson platform software, including TensorRT, cuDNN, CUDA Toolkit, VisionWorks, GStreamer, and OpenCV, which are built on top of L4T with LTS Linux kernel. Sample code was modified in accordance to the custom vision tensorflow model.

Proximity Sensing Subsystem
No changes were made to the proximity sensing subsystem.

Learnings/Comments
This prototype was successful and was able to detect all types of masks with an 87% success rate (more details in testing section). However, the device was unable to perform mask detection behind the user which is a necessary feature.

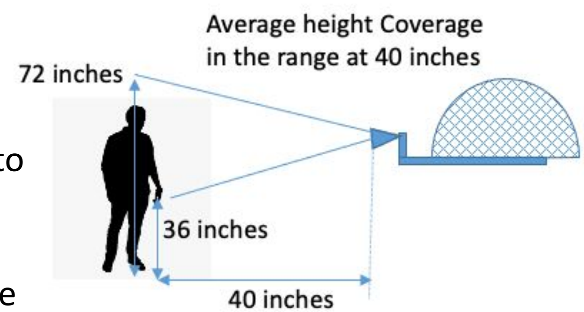
Prototype 2B ***(In Development)***	Goal: To explore how the LIDAR sensors can be replaced by two cameras (one in the front, and the other in the back) which will simultaneously perform mask detection and proximity sensing.



Testing Arc for all Prototypes

Testing Plan

In order to test the functionality of the Cat-Eye, a testing method was devised to analyze performance in the camera's field of vision from 90 degrees to 135 degrees (as depicted in the figure on the left). One participant would walk across the three arcs from points A-E and both the mask detection + proximity sensing systems were tested. On a data table, 0 was marked if the device did not function and a 1 was marked if the device did function. Three participants from ages 12 to 55 tested the product. The results and analysis are displayed below.



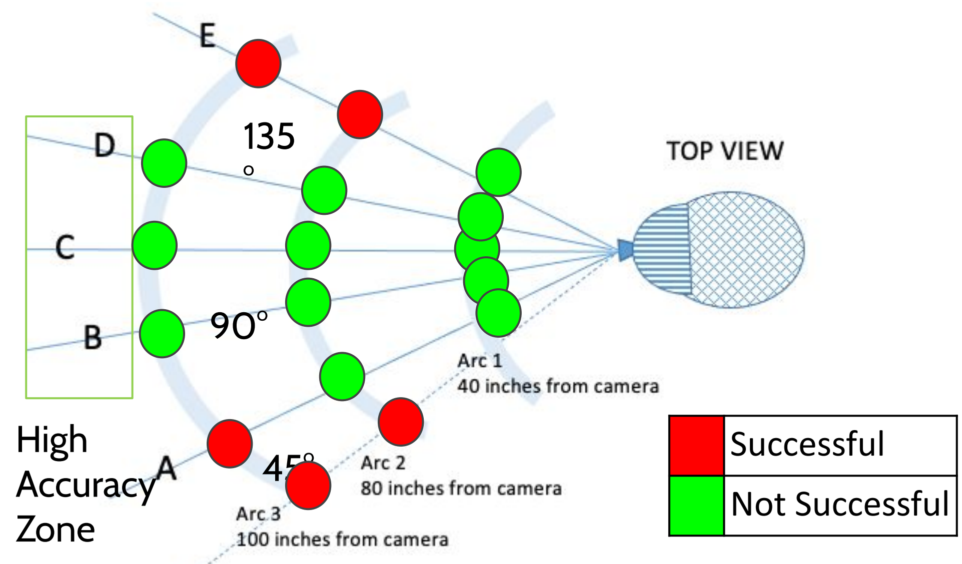
CAT-EYE Height Range

Testing Results

Based on the readings from three participants for Prototypes 1A and 2A, average success rates for each prototype were determined. **Prototype 1A had a 71% success rate while Prototype 2A had an 87% success rate**.

Prototype 3						
Trial 1	A	B	C	D	E	
Arc 1	1	1	1	1	1	
Arc 2	1	1	1	1	1	
Arc 3	0	1	1	1	0	
Trial 2						
Arc 1	1	1	1	1	0	
Arc 2	1	1	1	1	1	
Arc 3	1	1	1	1	1	
Trial 3						
Arc 1	1	1	1	1	0	
Arc 2	0	1	1	1	1	
Arc 3	0	1	1	1	1	Accuracy
	6	9	9	9	6	87%

Sample Data Table (Prototype 2A)



Geographical Analysis of CAT-Eye's field of Vision

Data Interpretation

Learnings from Prototype 1A

Prototype 1A did not involve IOT and had the most straightforward design. The Pixy Cam 2 served its purpose as a basic computer vision system for initial prototyping and determining the testing methodology. Although the device worked reasonably well, it was only able to detect blue surgical masks. Since masks come in all shapes and sizes, it is evident that AI needed to be integrated.

The LIDAR and vibrotactile feedback system for proximity sensing also functioned relatively well, and the hat vibrated when a person came within 2 meters of the user. However, the LIDAR sensor was found not to be very accurate beyond 1 meter.

Prototype 1B did not function well due to the limited processing power capacity fo the Raspberry Pi.

success rate
71%

Learnings from Prototype 2A

Prototype 2A with the Jetson Nano 2 gigabyte memory developer edition was very structured as Jetson Nano ships with JetPack SDK. Jetson Nano can also function as an edge device, and Azure Custom Vision was leveraged to create a TensorFlow model for mask detection. It is easy to export the model to Jetson Nano, and with a few configuration changes, mask detection can work efficiently. The use of IoT edge has tremendous advantages as I can potentially push another model to the same device to do a lot more than mask detection. The same device can be used as a safety helmet in any scenario. The accuracy of testing improved with Jetson Nano.

success rate
87%

Prototype 2B (In Development)

Prototype 2A with the 2 Gigabyte Jetson Nano was slow at times, and as a result, I contacted an NVIDIA engineer who told me to use 4 Gig Nano for better results. Since one can interface two RPI cameras to the 4Gig Nano, It made sense to use it as a final prototype. The use of the 4Gig Nano would allow for:

1. Better performance
2. Better range with front and back cameras
3. The latest Jetpack release has enhancements to help with computer vision modules
4. The microcontroller is certified with the Azure IoT computer vision modules
5. Ease of deployment with IoT Hub to the edge device would allow for many applications of the same hardware

Criteria/Constraint Analysis

The device was able to meet all of the criteria and constraints and achieved relative success. In addition, we were able to meet the "5 C's of Assistive Technology Design" which was established by the Assistive Technology Lab at Stanford University!:

1. **Comfort** - form fitting,flexible, hands free wearable
2. **Cosmesis** - Doesn't change the appearance of the user significantly
3. **Function** - With a success rate of 87%, it has high reliability in terms of its function
4. **Cost** - Costs less than $300, making it more economically accessible than other assistive device
5. **Cool** - The chassis can be customized to various shapes, colors and prints.

Use Cases and Applications

The prototype solution can have many use cases beyond Covid mask detection and alert for the visually impaired. With the right trained tensorflow export from IOT hub, one can use the same device in various scenarios like:

- Law enforcement and security personnel at the airports, hospitals, offices etc to monitor people who are not conforming to social distancing and masks guidelines.
- Construction site workers, bikers, soldiers, public safety officers can all us a customized version of CAT-EYE to meet their specific needs, specially since the helmet is capable of transmitting data based on IoT, that can be leveraged to significantly increase safety.

Novelty of Solution

While much work has been done to develop an effective and reliable way to monitor social distancing, little has been done to discover how it can be used for IoT-based assistive technologies for the visually impaired, which is what makes CAT- EYE unique. By far, the visually impaired population has been neglected during this pandemic, but this device attempts to restore their mobility back to pre-pandemic levels.

Project Video Link:

https://youtu.be/TZ02UoSkc_I

Future Prospects

Future steps will be taken by me to improve the efficiency and accuracy of the device. Below are a few examples of further research:

1. Utilizing a more powerful Jetson Nano would allow the CAT-eye to connect to multiple cameras and replace the need for a LIDAR sensor
2. Exploring other forms of human-device interaction such as audio output.
3. Exploring if this device can be solar powered
4. Exploring how this device can retrofitted to other wearables or be applied to a different disability demographic

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