Kartezyen Corp.

Aid for the Blind

Final Report

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Design Studio Section: 2

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Table of Contents

Executive Summary

Kartezyen Corp., a newly formed company, is composed of five committed and skilled engineers who are passionately working on a project titled "Aid for the Blind". This endeavor, focused on creating assistive devices, is not as straightforward as it seems due to the intricate engineering complexities it involves. However, overcoming these obstacles will significantly benefit both our clientele and our company.

The market offers a variety of products designed for visually impaired people, ranging from simple canes to more sophisticated devices akin to our projected end product. Still, many of these offerings are either too complicated for regular use or too costly for general availability. Our goal at Kartezyen Corp. is to bridge this gap by developing an inexpensive, user-friendly product that is accessible to people of all ages.

Though bringing an innovative, affordable product to life through the "Aid for the Blind" project is a formidable endeavor, our team is prepared. With our collective proficiency and experience across all necessary areas, we are equipped to address and resolve any challenges effectively and efficiently. Our team members understand the value of unity and are dedicated to preserving high standards of quality throughout the project.

Our main strategy in tackling this challenge involves a system centered around an image recognition algorithm. Operating on a powerful controller board, the system includes a high-definition camera, an ultrasonic distance sensor, and an audio system—all powered by rechargeable batteries—to assist users in their everyday life. The algorithm will undergo thorough training to detect common obstacles in everyday traffic, with the ultrasonic sensor aiding smooth user movement. Data from both the sensor and image recognition will be combined to ensure safe navigation. This information will be communicated to users via an audio subsystem, mainly through headphones.

Once the project is finalized, several deliverables must be achieved. The end product will be an easy-to-use device incorporating a camera, sensor, audio system, main controller, and power subsystem housed within a handy casing. The device's software will utilize the image recognition algorithm and sensor data to maximize user safety. Additionally, the device will come with pre-installed batteries for immediate use, and ongoing customer support will be on hand to address any issues.

The project is estimated to be completed within the next month. In terms of budget, we predict that $200 will be exceeded by a miniscule amount.

Introduction

2.1. Background of the project

Our world, though brimming with beauty, also presents numerous dangers and obstacles for its inhabitants. While many people can overcome these challenges using their innate senses, some face heightened difficulties due to sensory disabilities. Notably, blindness or visual impairments can dramatically increase the risk of accidents and make navigating a world created for sighted individuals remarkably complex.

Recent years have seen an upsurge in endeavors to enhance the lives of those with visual impairments. Nevertheless, many of these innovations are either insufficient or not widely adopted, emphasizing the need for assistive devices that amplify users' awareness of their surroundings and aid decision-making in day-to-day life.

Our company's mission is to assist visually impaired individuals by offering a flexible and dependable set of tools that can be effortlessly applied in various situations. We are primarily focused on developing a device that supports users in navigating their environment without being intrusive or disruptive, and that incorporates cutting-edge technologies, staying true to our corporate mission.

Over the past few months, we have diligently pursued this ambition, acquiring crucial knowledge for our vital subsystems. We have delved into image processing and obstacle detection methodologies during this time. Despite the obstacles we encountered, we have built up sufficient expertise and successfully conducted module test and integrated system demonstrations under our supervisor's guidance. We are currently in the process of completing the final prototype, a powerful realization of our vision for this project dedicated to assisting visually impaired individuals.

2.2. Problem statement

Our primary goal is to devise a dependable and sophisticated image processing system capable of scanning the surrounding environment through a camera and identifying daily life elements such as pedestrian crossings, traffic lights, and vehicle flow. This constitutes the main hurdle for our project. Over recent months, our focus has been on image processing methodologies that satisfy these prerequisites. Throughout this timespan we fully accomplished our targeted result, and currently we can successfully detect pedestrian crossings, red/green pedestrian traffic lights and cars on the road.

A crucial part of the project involves identifying obstacles that stand at least 25 cm tall, which could obstruct an individual's path. To fulfill this need, we propose the use of a single ultrasonic sensor, positioned at a 60° angle from the vertical axis. Our testing indicates that this arrangement will effectively detect any obstacles in the user's path.

The main computational challenge for our software lies in gathering all the collected data and warning the user of potential hazards while suggesting a safe path through auditory guidance. To this end, we structured our final algorithm to satisfy these needs. Utilizing a state machine, our final algorithm helps the user to pass the road whenever it is initiated by the user while always checking for obstacles that might be in front of the user.

The final challenge we must overcome pertains to the seamless integration of all these subsystems to ensure user-friendly operation and minimal disruption to the user's daily routine. This issue also introduces a mechanical challenge, as we must accommodate all subsystems within an appropriate casing designed to be a small, compact box with minimal cables and buttons protruding from it. Our final product has the mechanical structure that encloses all our hardware in an efficient manner with all the required parts.

2.3. Scope and organization

In the executive summary section, we've given an overview of the project. This is followed by background information, detailing the problem we're striving to solve and the current progress of the project. Subsequently, we delve into the system design, outlining its requirements and modifications made.

Following that, we evaluate how the subsystems mesh together, along with a verification of their adherence to the established requirements. Test results and how we've managed resources are also covered.

Then we will disclose the deliverables we promised at the beginning of the year and situation of our budget, and the impacts of our project.

In conclusion, we summarize the essential elements included in our critical design review report. This structured approach provides a comprehensive understanding of our project's trajectory and progress.

We will also provide a user manual at the appendix of our report which will detail the usage procedure of our Axis device.

System Design

Kartezyen Corp.'s *Aid for the Blind* device "Axis" includes five sub-modules that interact as shown in the below chart:

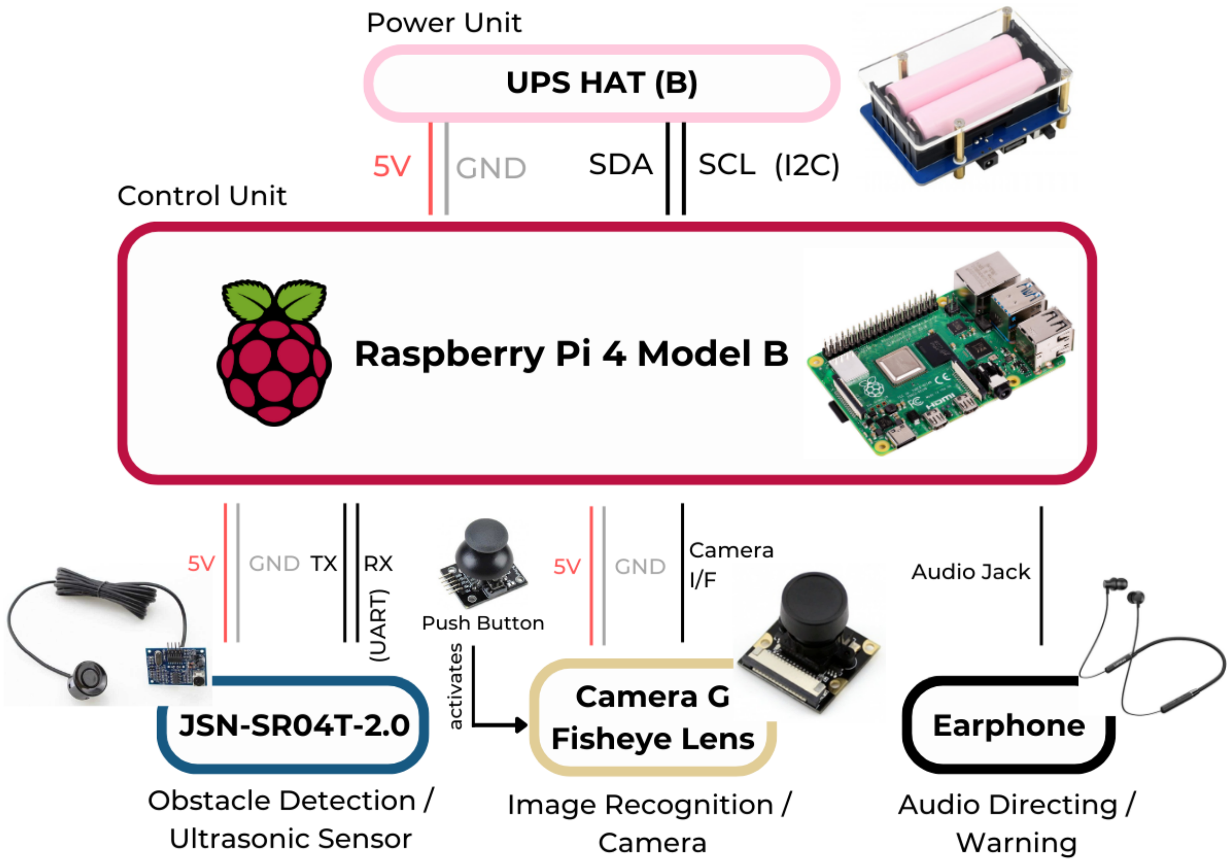


Figure 1: Communication through sub-units schematic

While the main algorithm operates at the control unit, Raspberry Pi gets the necessary information for the image recognition and the obstacle detection units from the ultrasonic sensor and camera respectively. After processing the information warns and directs the user via earphone.

The final product is placed in a single wearable device that can be worn with a chest strap that is adjusted according to user's height.

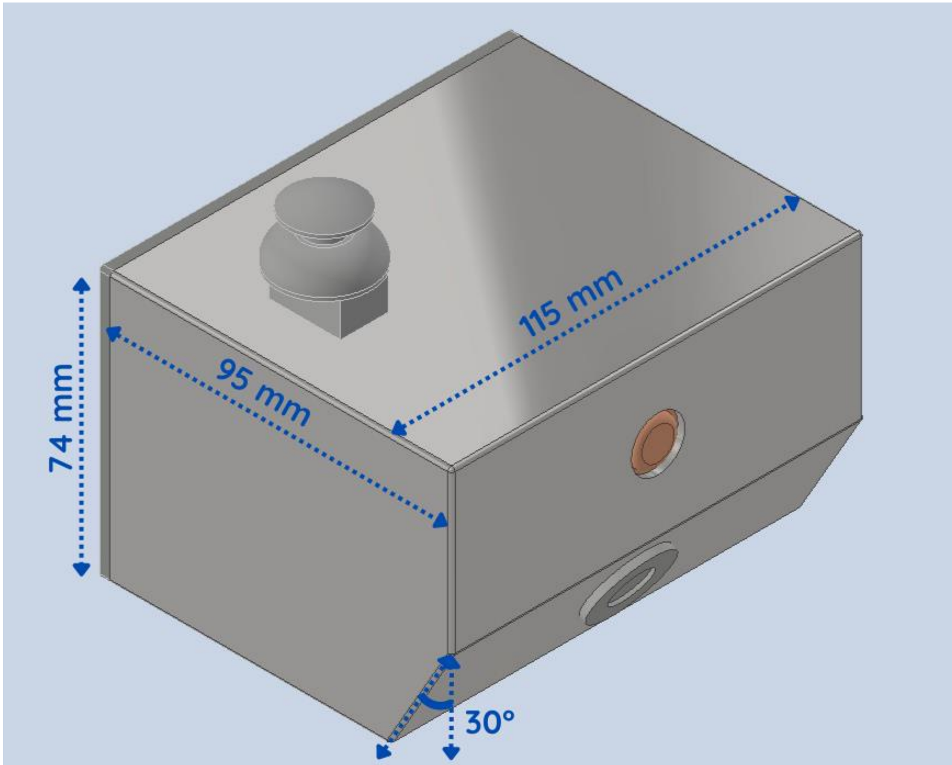


Figure 2: Technical drawing of the device

The dimensions for the case that includes all sub modules are 115 mm * 95 mm * 74 mm. The device has a weight of approximately 413 g.

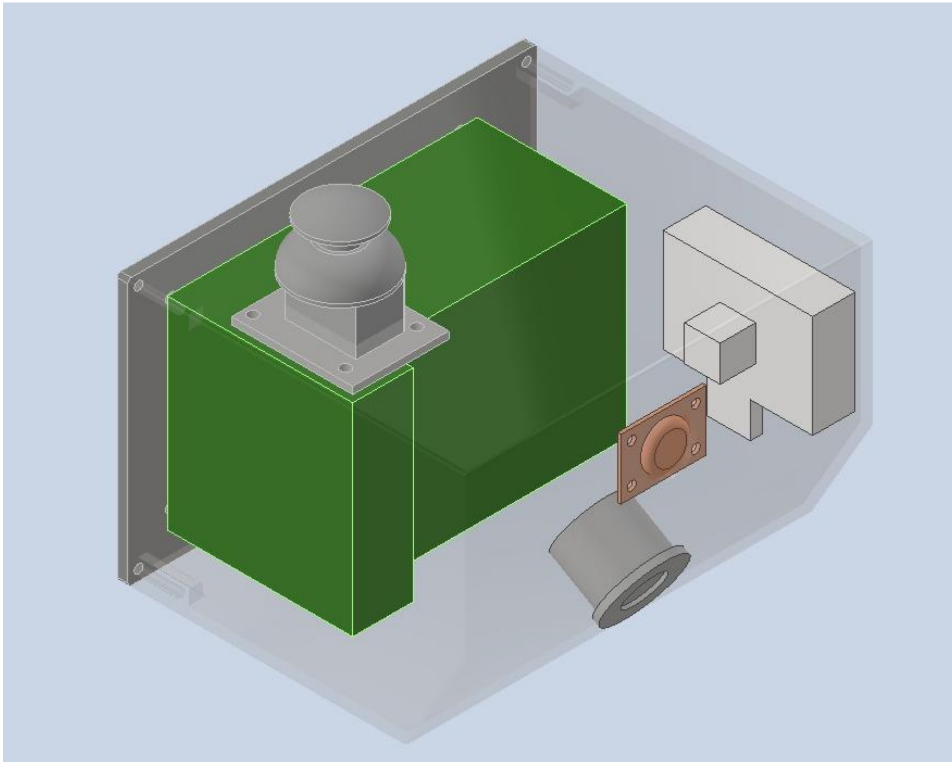


Figure 3: Technical drawing of the modules

The hard case for the device is printed through a 3D printer. The material for the case is PLA; which has both strength and elasticity features. It is easy to fit the device on; since it has also elasticity, it is hard to break it.

Figure 4: Kartezyen Corp.'s Aid for the Blind wearable device: Axis

The vacancy for the charging port, earphone jack and USB / Ethernet ports are left on purpose so that it is easier to reach from the outside.

The overall algorithm that is used in the device is shown in Figure 5.

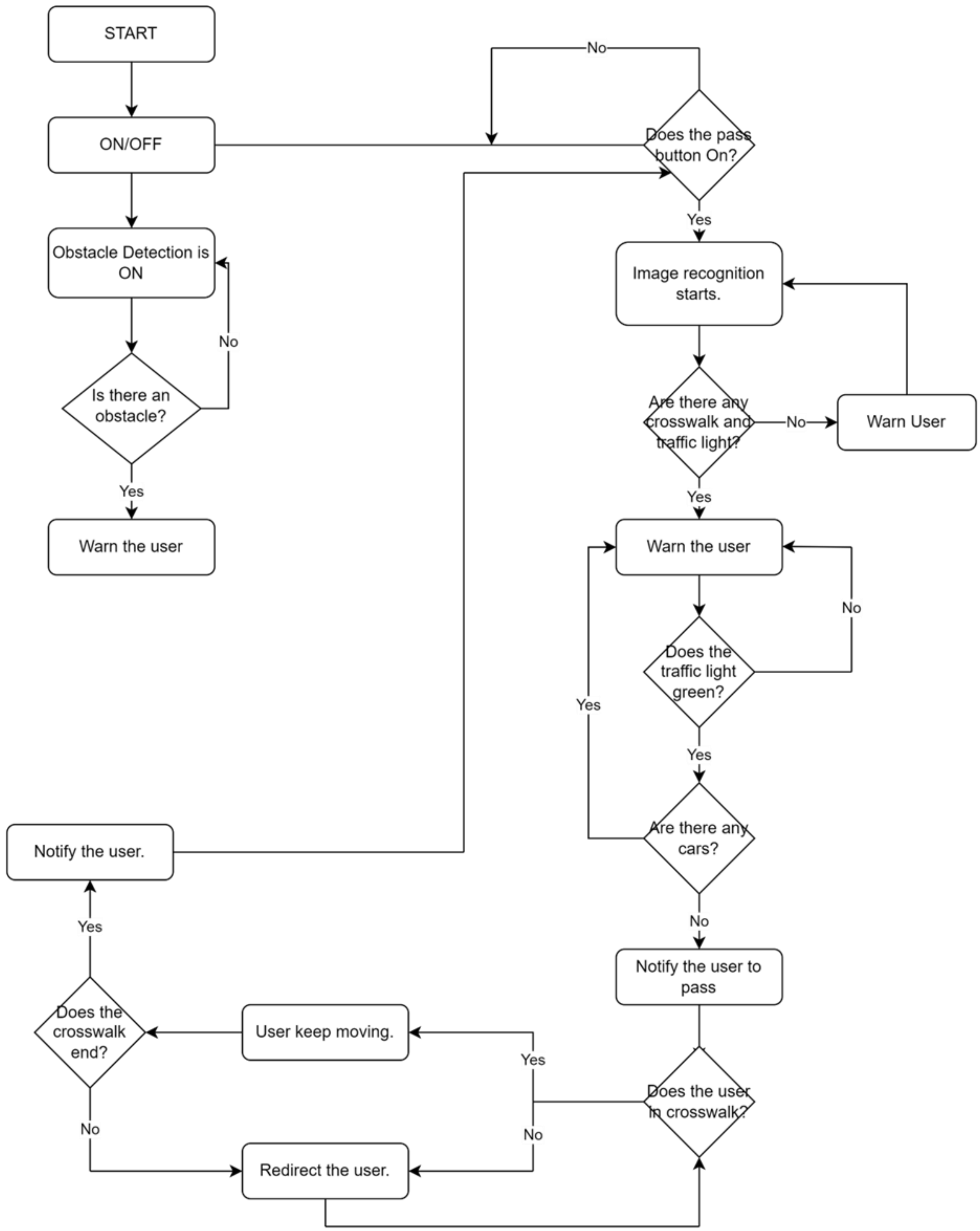


Figure 5. The flowchart that shows the main algorithm

Obstacle Detection Subsystem

System Description

Our system has two primary objectives: identifying obstacles and determining the distance between the user and pedestrians. In order to accomplish this, we employ ultrasonic sensors for perceiving and measuring distances. The ultrasonic sensor operates in multiple modes, but we specifically utilize the no resistance connected mode. In this mode, the sensor emits a brief ultrasonic pulse that is then reflected back by an object. The sensor receives this signal and converts it into an electrical signal. After the echo dissipates, the pulse is transmitted again, and the time period of this cycle is used to calculate the distance. To measure the distance, a trigger pulse with a width of 10μs is sent to the signal pin, and the ultrasonic module generates eight 40kHz ultrasonic signals. The duration of the echo pulse is directly proportional to the measured distance, which can be determined using a specific formula.

$$\textit{Distance (cm)} = \textit{Pulse Width } (\mu s) / 58$$

When there is no obstacle detected, the output pin from the controller will provide a high-level signal that lasts for 38ms. This signal indicates the absence of any detected obstacles. After the measurement process, the echo port will automatically transition to a low-level state after 60ms.

Solution Procedure

The ultrasonic sensor is employed to measure the distance between the user and pedestrians or objects that are taller than 25 centimeters. It is positioned on the device at an angle of 60 degrees with respect to the vertical orientation. Assuming the device is placed at a height of 120 cm, and a 25 cm obstacle is utilized, let's consider the scenario where the distance between the user and the obstacle is 170 cm.

In this setup, if the distance between the obstacle and the user extends to 2.5 meters or the distance between an approaching pedestrian and the user reaches 1.5 meters, this unit will transmit the data to the speaker unit and initiate a warning mechanism until the distance between them reduces to 72 cm.

Measurements are taken at intervals of 250 ms, providing continuous monitoring and assessment of the distances involved in the surroundings.

During the development of the device, the design took into consideration the average human height of 170 cm. The sensor is positioned at a height of around 120 cm from the ground, above the user. Considering that the typical human step falls within the range of 60-70 cm, any data generated by the user's steps is deemed irrelevant. Consequently, calculations were performed, taking into account a minimum object length of 25 cm. As a result, measurements within 72 cm in front of the user will not be considered or taken into account in the device's operation.

The main purpose of the Obstacle Detection subsystem is to notify the user when pedestrians or objects are in close proximity, posing a potential hazard. It is not necessary to know the exact distance to the oncoming pedestrian or the obstacle ahead, unless they are close enough to be a danger. Once this proximity is reached, the Audio Warning System will inform the user about the presence of a hazardous obstacle, rather than providing the precise distance in meters.

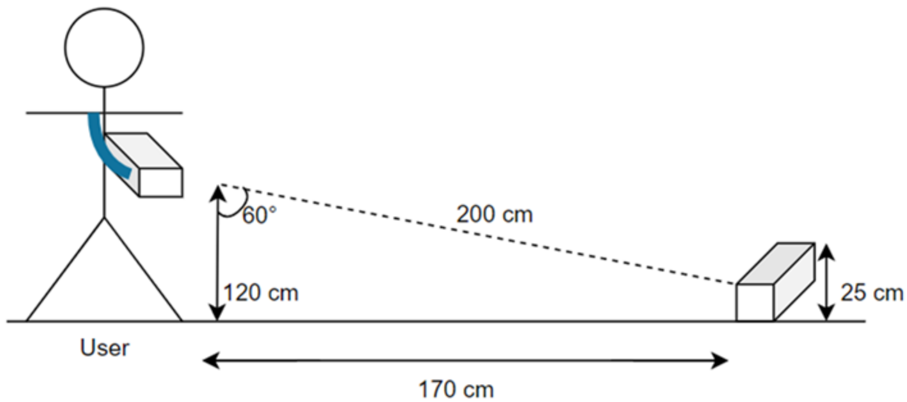


Figure 6. Representation of the Sensor Position

Based on these considerations, we determined that a single sensor positioned at a 60-degree angle with respect to the vertical orientation, when the device is placed at a height of 120 cm, can effectively detect objects taller than 25 cm from a distance of 250 cm. Additionally, we discovered that the sensor can detect an obstacle in front of the user when an oncoming pedestrian comes into view at a distance of 150 cm.

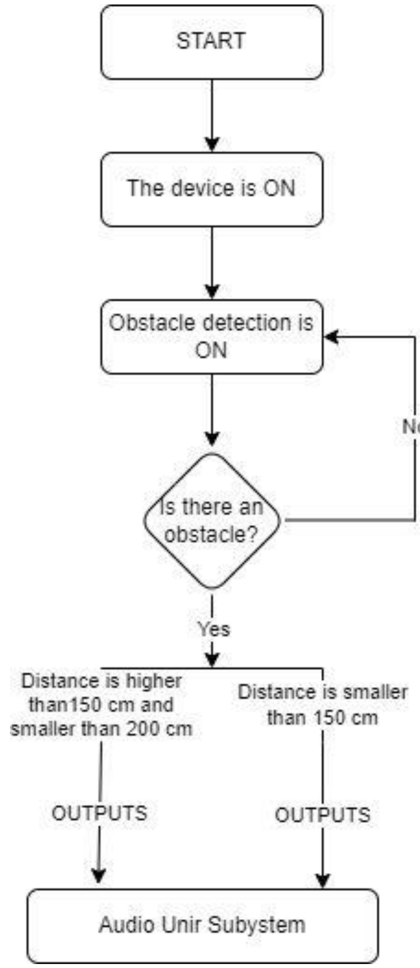


Figure 7 - The simple block diagram for the obstacle detection subsystem

Table 1 – Flow Procedure of Obstacle Detection Subsystem

Procedure	Operation	Description
1	Device Initialization	Initialize the device when turned on
2	Continuous Monitoring	Continuously monitor the surroundings for obstacles
3	Obstacle Detection	Detect obstacles within the specified range
4	Audio Warning - Obstacle Detected	Issue a warning about the detected obstacle
5	Distance Check	Check the measured distance
6	Audio Warning - Close Proximity	If distance < 150 cm, issue a warning about close proximity

7	Audio Warning - Warning Zone	If1 50 < distance < 200 cm, issue a warning about the warning zone
8	Image Recognition Data	Capture data from the image recognition subsystem
9	Audio Warning - Directional Guidance	Provide directional guidance based on captured data
10	Completion	Complete the obstacle detection process
11	Continuous Operation	Continue monitoring and repeat the process

Design Modifications

In the initial design phase, we considered using two ultrasonic sensors in the subsystem. One sensor would measure the distance between the user and pedestrians, while the other would detect obstacles in front of the user and measure the distance between those obstacles and the user. However, we eventually concluded that we could solve the obstacle detection issue by reducing the number of sensors to just one in the final version of our design.

By reducing the number of sensors to one, we have achieved a lighter and more cost-effective product. This approach has made our product more user-friendly.

System Requirements

Functional Requirements

- The device should detect obstacles, including people walking on the street, pedestrian crossings, and traffic-related objects in the user's vicinity. It should recognize indicators of a pedestrian crossing such as signal displays, road markings, streetlights, and pedestrian-related traffic signs. Detection should involve measuring distances and determining the positions of these objects relative to the user.
-

Performance Requirements

- The device should provide a warning to the user when encountering an obstacle that is 25 cm high.
- The device should perform accurate measurements from a distance of 1.5 m, with at least 70% accuracy, and provide correct voice commands during daytime and clear weather conditions.
- The device's field of view should closely match that of human eyes, approximately a 120-degree horizontal span.
- All obstacles and traffic-related objects within the device's field of view should be detected, and the user should be warned about road safety.

Image Processing Subsystem

System Description

This subsystem is responsible for obtaining information about a number of classes that are in the angle of view of the device user. It determines whether or not pedestrian crossing, green and red pedestrian traffic lights, person or car exists in the angle of view. Therefore, its input is the frames that come from outside via the camera, and its output is the detection results that are processed in a microcontroller unit. These results are sent to the audio unit subsystem to produce voice commands. The overview of the image processing subsystem is on a block diagram in Figure 8.

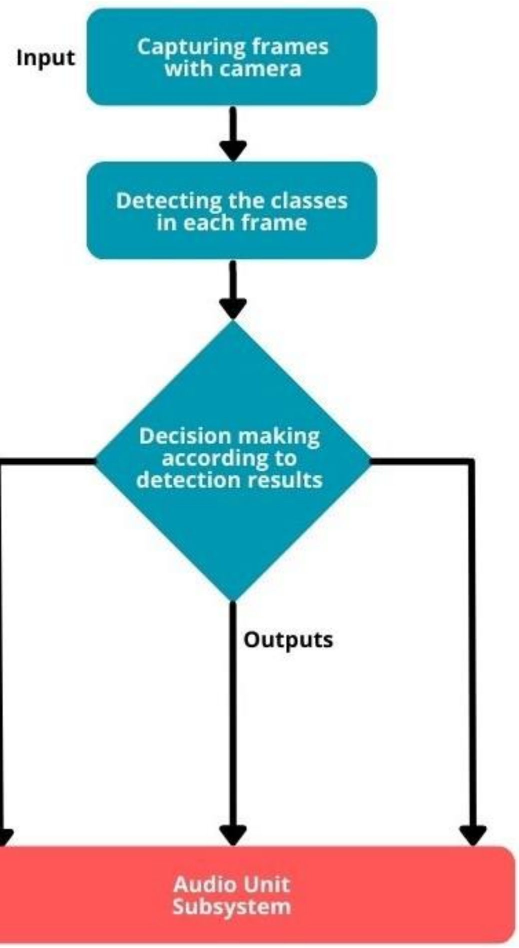


Figure 8. The block diagram for the image processing subsystem where its outputs are the inputs for audio unit subsystem

Image processing subsystem consists of a camera and a microcontroller, which is Raspberry Pi. The camera that we use is a wide lens Raspberry Pi Fisheye Camera to satisfy the 120 degrees of angle of view requirement by its 160 degrees angle of view. Thanks to the wide angle lens, turning the camera to the left and right direction for a user at the side of a road is not required for checking the existence of a class of objects such as pedestrian crossing and traffic lights.

The input to the subsystem is the photograph and/or video frame that is captured by the camera. A frame in real time depicts the street view from the angle of the view of the camera. Frames are sent to the object detection model one by one. In Raspberry Pi, there is software that detects 5 classes of objects which are shown in Figure 9.

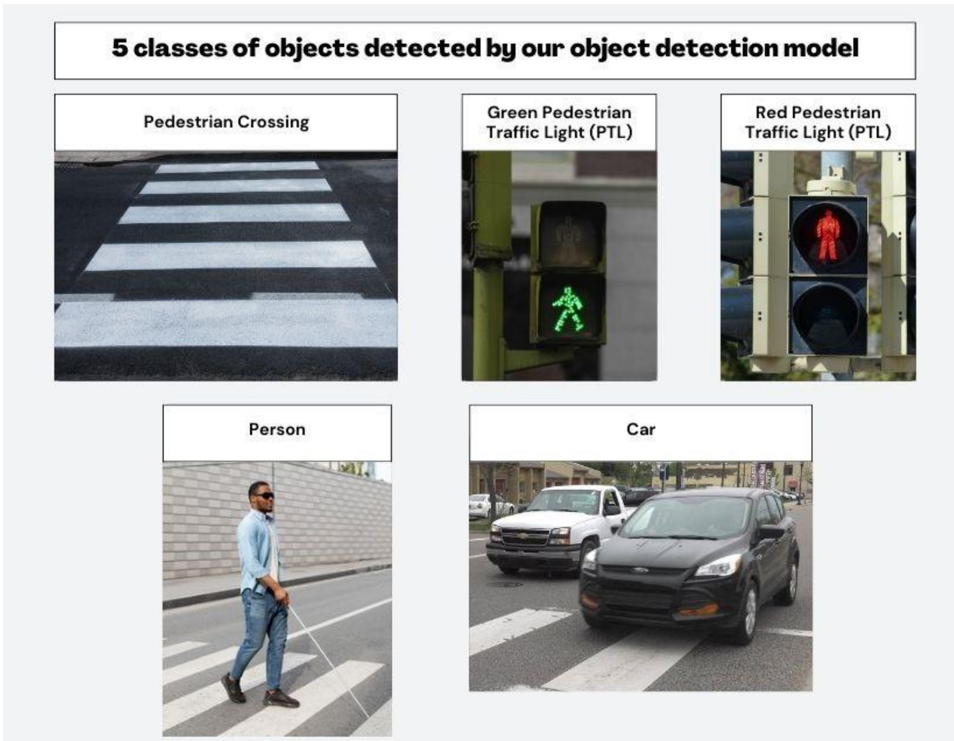


Figure 9. Classes of objects that can be detected by our device

The method that the software uses is called deep learning, or convolutional neural networks (CNNs). A CNN consists of mainly four parts as in Figure 10: Input Layer, Feature Extraction Layers which include convolutional filters, Classification Layers, and Output Layer. Since the CNN has such a multilayer structure, a shallow CNN with fewer layers gives faster classification results. Because our device makes real-time detections, it is better to have a small inference time which requires a fast CNN.

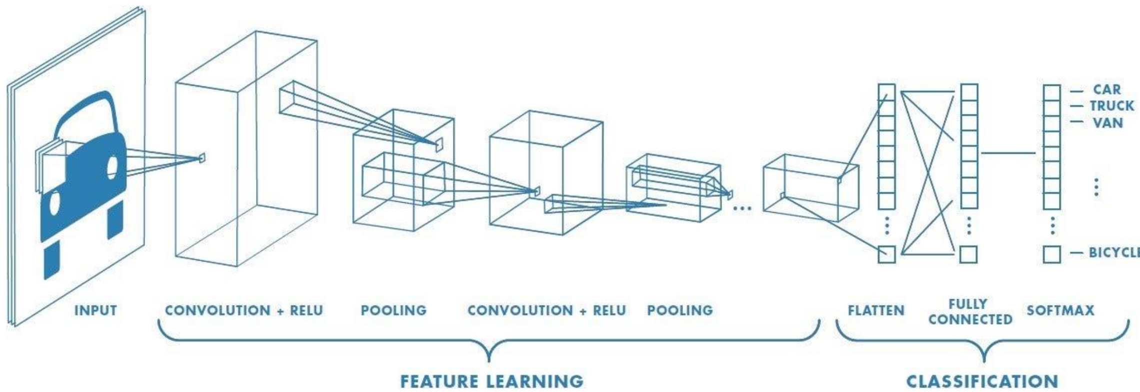


Figure 10. Input Layer, Feature Extraction Layers, and Classification Layers in a CNN

To create a CNN, a pre-trained model is usually used to decrease the time to produce a model from scratch. This procedure is called transfer learning. To create smaller layers in the Feature Extraction Part of a CNN, a dataset that consists of labeled images and/or videos is required.

Before starting a training, it is realized that there are a lot of parameters that affect the accuracy of CNN model. The most important two of them are batch size and the number of epochs. Batch size is the number of images that are used in a training step, and the number of epochs is the number of training steps that passes through the entire dataset. To obtain more accurate CNN models, small batch size and large number of epochs should be used as much as possible.

Solution Procedure

Dataset generation and training are done on a computer, and the weight file of a trained model is transferred to Raspberry Pi. Then, an object detection algorithm makes inferences by using the weights. All these steps are described in a detailed way in the Appendix of Image Processing Subsystem.

Image processing subsystem will only work when the button on the top of the device is pushed. This makes the processor usage of RPI more efficient by not working all the time when the device is on.

Generating a dataset:

We generated a unique data set consisting of training, validation and test parts in Roboflow, which provides an updatable data set environment. We used the images from the streets under the pedestrian and vehicle traffic, mainly from two publicly available data sets. Also, for indoor tests, we used the photographs of pedestrian crossing, red and green PTLs that are made of construction papers and cardboards in our training part of the dataset.

For the training part, we chose images that have at least one of the five classes, which are pedestrian crossing, red and green PTLs, person, and car.

Training the dataset:

We used YOLOv5 algorithm to create a CNN by using training and validation images for the data set. Training and validation images are the ones we keep in Roboflow environment, and they all include at least one of the five classes. After the training process, the program gives a trained model weight file "best.pt".

In addition, we used 4 augmentation methods to the training images. These methods increase the number of training images. Dataset details is shown in Table 2.

Table 2: Dataset Partition and Details

Part of Dataset	Number of Images	Augmentation Methods Used
Training	794 (89 %)	- Horizontal Flip - 90 degrees rotation - Grayscale - Bounding Box Blur
Validation	59 (7 %)	Not Applicable
Test	43 (5 %)	Not Applicable

Using the trained model on RPI:

The trained model weights will be deployed to the device, and then we can detect the classes of objects using the camera, RPI and the trained model by running a Python code.

Design Modifications

At first, we used a YOLOv5 model with 5 classes of objects that did not have the indoor photographs for pedestrian crossing, red and green PTLs. After having updated our dataset and labeled new images, we have increased the number of images in training dataset by adding new cardboard made object photographs. Table 3 shows the main parameter values for training.

Table 3: Parameters for Training in YOLOv5

Batch Size	12
Number of Epochs	200

In CDRR, we used a batch size of 16 and 150 epochs, and we obtained 66 % mAP, which was fairly close to 70 % accuracy of detection.

By using our new parameter values in Table x, we achieved 75.9 mAP which is more than 70 %, which satisfies our accuracy requirement for the image processing subsystem.

System Requirements

Functional Requirements

The subsystem should detect pedestrian crossings, green and red pedestrian traffic lights, people walking on the street and cars on the road.

Performance Requirements

The accuracy of the detections should be at least 70% in mean Average Precision (mAP) metric, which is used in object detection accuracy.

The detection time for classes in real-time video frames should be at most 5 seconds before starting to give a voice command.,

Power Unit Subsystem

System Description

The power unit sub module consists of UPS HAT (B) device that is specific to the Raspberry Pi and two 18650 3400 mAh batteries. The module provides 5V of voltage supply and communicates through I2C to give the information of remaining battery.

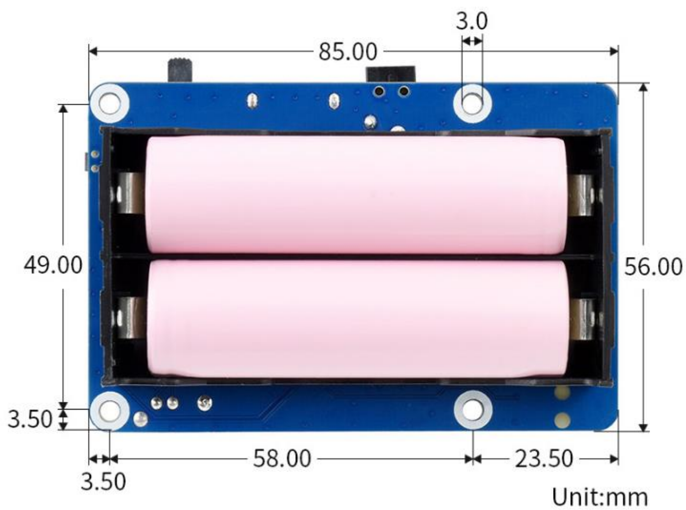


Figure 11: Power module and batteries

Solution Procedure

The module is mechanically fixed to Raspberry and gives the needed power through 5V pin. Since the module has a communication IC on it the necessary battery info is obtained with Python code via I2C protocol.

System Requirements

Functional Requirements

- Should have universal charging port
- Easily mounted
- Communication for remaining battery

Performance Requirements

- 5-10 hours of battery life
- Minimum of 5000 mAh battery capacity (by calculations)

The tests conducted for the power subsystem is provided below:

Table 4: Power consumption table

Condition	Current mA (5V)	Power (Watts)
Raspberry Pi on idle mode	450	2,25
Raspberry Pi with only obstacle detection	520	2,6
Raspberry Pi with image detection	900	4,5
Estimated with fully operating overall system	970	**4,85**

Our requirement for the power unit was 5 to 10 hours for a satisfactory result.

Audio Unit Subsystem

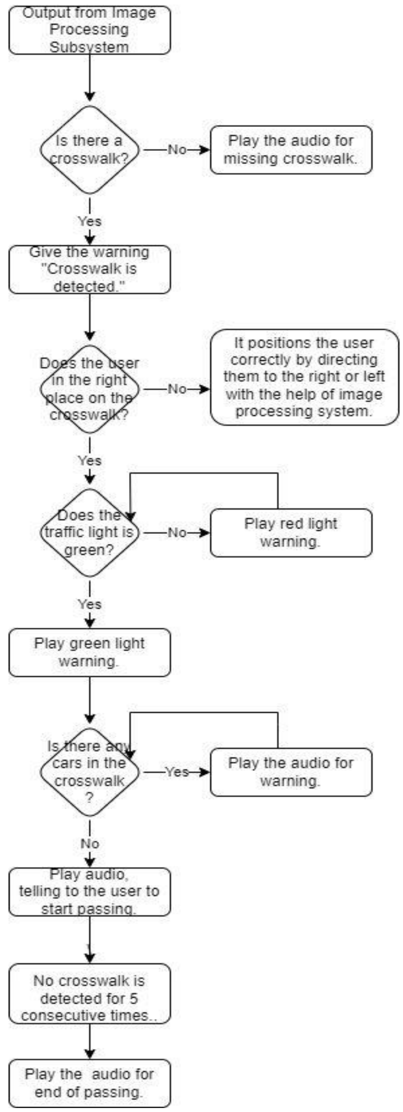
System Description

The audio unit system consists of externally acquired headphones that are linked to the Raspberry Pi via the headphone jack connector found on the board. Our experiments have demonstrated that this port is user-friendly, making it a seamless addition to our complete unit for delivering alerts to the user.

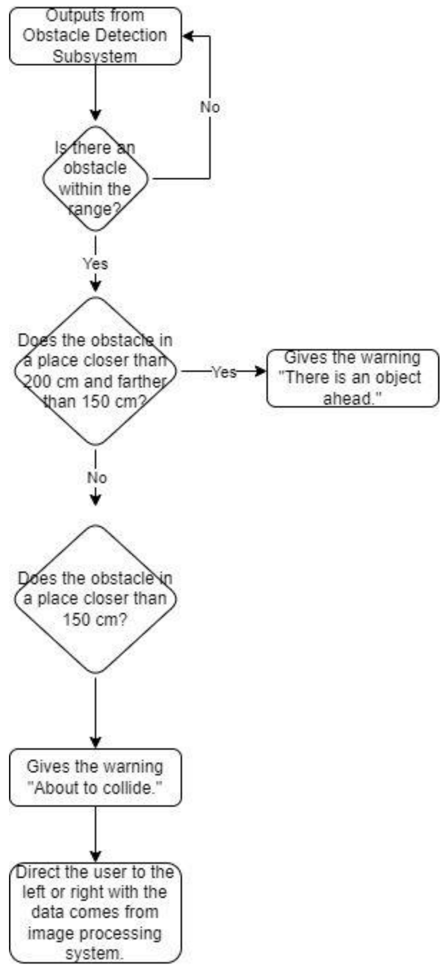
Solution Procedure

It works in partnership with audio warning system image processing and obstacle detection sub systems. There are different warnings to be given by the audio unit system according to the outputs from these systems. These warnings are available on the raspberry and these voice commands are transmitted to the user with the help of a headset.

Flowchart That Shows The Relation Between Image Processing Subsystem and Audio Unit System



Flowchart That Shows The Relation Between Obstacle Detection Subsystem and Audio Unit System



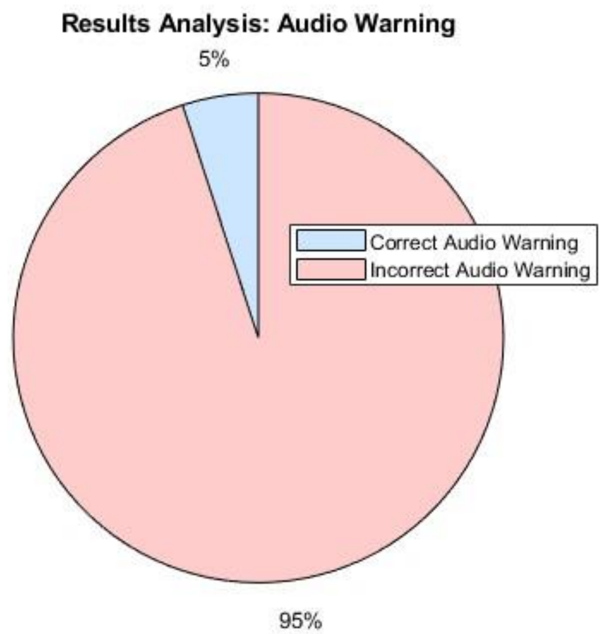
System Requirements

Functional Requirements

This system alerts and instructs the user based on the information received from obstacle detection and image processing systems.

Performance Requirements

The user should receive voice commands approximately one second after the completion of detection and recognition.



Design Modifications
In our trials we used Google Text to Speech (gTTS) API to create mp3 files for voice commands. However, in the final version of the project, we will use the audio files that we have created with our own voices instead of the pre-existing sound files.

Design Modifications

The design we described in the Critical Design Review Report (CDRR) is completely unchanged during the period between these reports. During this period, we conducted further tests and integration procedures for our device and we saw that our design is sufficient for our requirements, and therefore we haven't done any modification on it.

Test Results

Tests at Subsystem Level

Test of Obstacle Detection Subsystem

We conducted some tests for this subsysem. Here is the results of our one of testes.

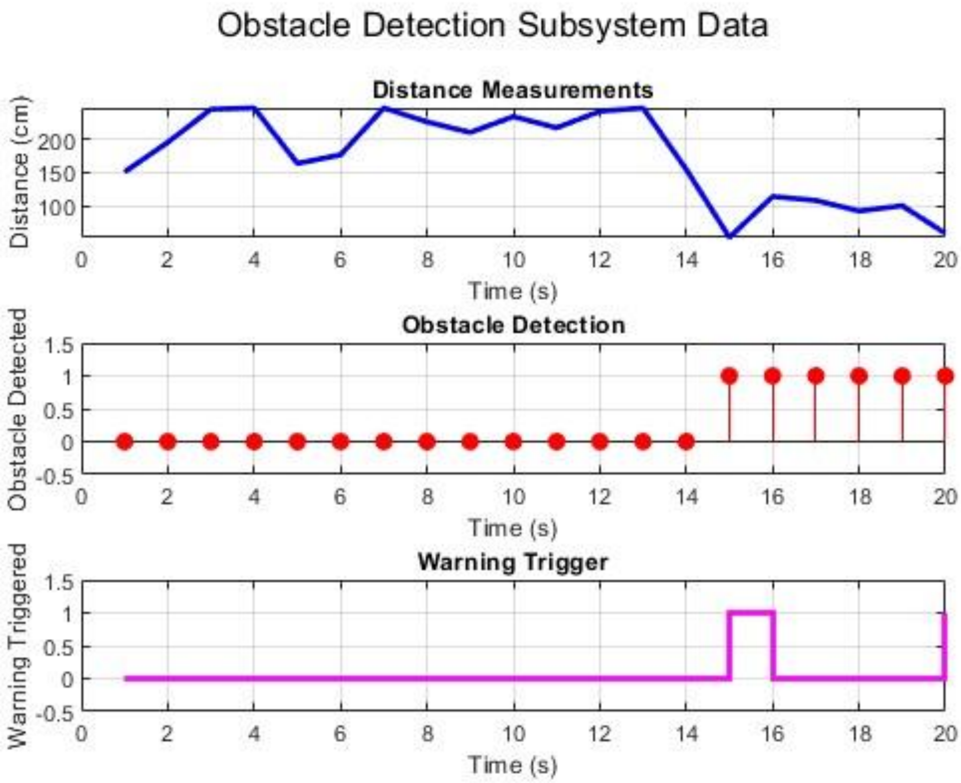


Figure 12- Graphs of Disance, Detection and Warning Trigger

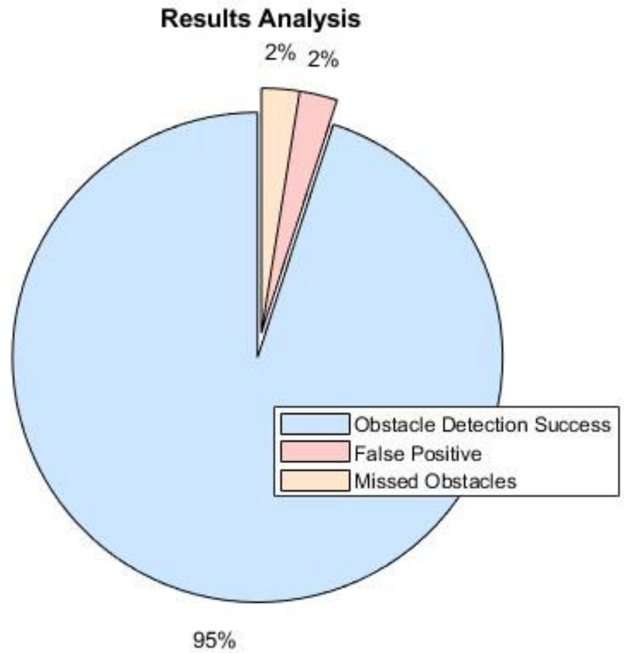


Figure 13 – Piechart graph of the Results

As can be seen from these resulting data, we can say that our obstacle detection subsystem exhibited a hiigh success rate above the 70% in detecting the obstacle and measuring the distance between the user and the obstacle.

Test of Image Processing Subsystem

We made a test with 43 images and 2 videos on RPI device by using YOLOv5. The test details are presented in a test document Appendix of Image Processing Subsystem. An example test result can be seen in Figure 14.

Figure 14. An example test frame detection result

The mAP for our test with RPI device is 0.759, which means 75.9 % accuracy satisfying the requirement of our device.

Results and Analyses of Performance Tests

- <u>Inference time of the device:</u> Passed the performance test.
  This time is the total time elapsed until a voice command starts after a detection by the camera.
  The device takes photographs every second (1 frame per second) and makes inferences by using the object detection model. The inference time for a frame is between 1000 – 1500 ms (1 – 1.5 second) as seen

in Figure 15. Overall, the total time for inference is 2 – 2.5 seconds, which is satisfactory (less than 5 seconds) according to our metric of high-speed in the Proposal Report.

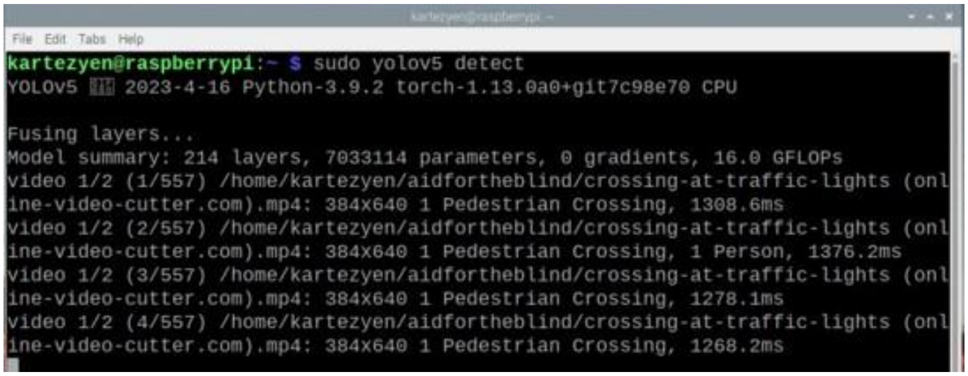


Figure 15. The inference time of each frame in the RPI terminal in a video test

Deliverables

Kartezyen Corp.'s "Aid for the Blind" project aims to deliver an innovative and affordable assistive device for visually impaired individuals. Our team of dedicated engineers will develop a user-friendly product incorporating an image recognition algorithm, a robust controller board, a high-quality camera, an ultrasonic distance sensor, and an audio subsystem. The deliverables include a complete device with pre-installed batteries, accompanying software for enhanced safety and navigation, and ongoing customer support. Through our expertise and commitment, we seek to revolutionize the assistive device market and improve the lives of visually impaired individuals.

Hardware

With a focus on user comfort, our designed hardware enables our users to access the following features:

Designed with user-friendly features using the Braille alphabet, our product ensures accessibility and ease of use for individuals with visual impairments.

We offer our users a product that combines an RGB camera, an ultrasonic sensor, a speaker, and a main controller, providing ease of use and portability.

All the equipment, including batteries, headphones, and a carrying strap, are provided to our customers by us.
The necessary charging cable for the battery is also provided to the customer along with our product.

Software

Our users will have access to both wearable hardware and software system.
Along with the software system, we offer our users the following features:
Detection of pedestrian crossings, traffic lights, and vehicles.
Identification of obstacles along the user's path.
Informing and providing auditory guidance to the user based on the detected information.

Services

The device is hand-delivered to your address within 1-2 working days.
Our customer care team offers user training during the initial delivery to ensure a perfect fit.
We provide 24/7 availability via phone or WhatsApp hotline for any technical or other challenges the user may face.
We welcome any feedback or updates regarding the device's usability and are committed to working collaboratively with the user to make it the most user-friendly product ever.

Documents and Media:

Our comprehensive support includes providing the "User Guide for Aid for the Blind" manual in both printed and electronic formats which is written in Latin and Braille Alphabet.
We supply a helpful audio tutorial that closely resembles the training provided by our dedicated customer care team.

Budget

Equipment (with changes)	Current Cost ($)
Raspberry Pi 4 Model B	**80**
JSN-SR04T-2.0	**5,28**
Raspberry Pi Camera G Fisheye Lens	**32,89**
UPS HAT (B) Power Unit	**28,37**
2 x 18650 3.7V Panasonic 3400 Mah batteries	**16,44**
3D printed case + neck strap	**25**
Earphone	**5,35**
Shipment	**10,69**
Total	**204,02**

Safety

Our device is designed by keeping visually imparied people in mind therefore we pay extra attention to the safety of our customers since we want our customers to feel safe while using our device in their daily lives. To this end, we designed our device's mechanical parts as strong as possible while keeping it as light as possible to prevent any discomfort.

Also we made sure that our subsystems are working correctly on numerous tests to prevent any unexpected behaviour of our system. From all these, we can confirm that our device works as best as with it can the utmost safety of the user in mind in the boundaries and settings we declare on our reports.

Impact

Societal Impact

Our product is designed to be the number one supporting device choice for the visually impaired people. While it can be used on its own, its best use is when it is used with a traditional cane to give additional feedback to the user for the situations that our device falls short.

As for our subsystems, our image recognition algorithm can be used in a variety of applications where detecting a thing or a being is necessary. This can be for a security system, an automatic feeding system for pets etc.

Environmental Impact

On the environment side, we can assure our users that we are using products that are really safe for the environment. To this end, we chose our material for the mechanical design to be biodegreadable and we purposely included rechargeable batteries to prevent additional damage to the environement that is caused by the old, depleted batteries.

Conclusion

In this report, our team at Kartezyen Corp. delves into a thorough analysis of our finalized design for the "Aid for the Blind" project. This project's objective is to create a wearable device that augments the ability of visually impaired individuals to navigate streets safely amidst the pedestrian and vehicular movement.

The core functionality of this device is to aid users in crossing pedestrian lanes while persistently surveying the environment for potential obstacles. We accomplish this through an image processing subsystem and an obstacle detection subsystem. We have detailed the overarching system and subsystem designs, including the detailed information for our final product. Our test outcomes are encouraging and sufficient to trust our final product.

For now, we have settled on our design for the project and successfully performed module test demonstrations for our vital subsystems and our tests for our overall integrated system.

In the past few months, we have endeavored to make the most of our time and broaden our expertise, especially in the fields of image processing and recognition. From all this effort, we finally produced our final prototype for the Aid for the Blind project named Axis.

Kartezyen Corp. is strongly convinced that the "Aid for the Blind" project will streamline daily life for those with visual impairments by decreasing their dependency on others for movement and navigation. Moreover, this affordable device will enable them to engage more actively in social life.

Appendix 1: User’s Manual

To provide the best user experience, we tried to minimize the actions necessary to operate Axis. For this purpose, our device currently only includes one button and one switch. The switch is used for opening and closing the device’s power and the button is for initializing the image recognition of the device. The process of our device is fully automatic and keeps working until the passing of the crossing is completed by the user. Device operates using the batteries in the enclosing case, these batteries are rechargeable through the ports on the case. Also for the ease of use, all of these features will be written in Braille on our device.

The following is the basic procedure to use the device:

- Device is initialized by switching the on/off switch. The obstacle detection starts and warns the user for any obstacle present in the user’s path.
- The user presses the button when crossing the street is desired.
- The image recognition unit searches for pedestrian crossings each time the button is pressed and warns the user when detected.
- The device checks for whether the crosswalk is centered and directs the user to move to the right or left to center the crosswalk.
- The image recognition checks for the pedestrian’s traffic light; when the light is red warns the user hold, when the light turns green allows the user to pass, if no cars are present on the crossing.
- The obstacle detection unit checks whether any obstacle on the crosswalk when the obstacle is present, the user is warned to position himself/herself with the help of still-operating crosswalk centering algorithm.
- The image recognition unit continues taking images, when the pedestrian crossing is last seen 10 seconds ago the device warns the user that the crossing is over.

- The crossing operation is successfully finished and the device waits for another command.

Appendix 2: Test-1