Walking Wise
Camera Sensor Smart Cane

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Abstract– The goal of this project is to engineer a modernized hand-held device outfitted with advanced input sensors and a revolutionized feedback system that will change the way the visually impaired traverse their environment. According to the World Health Organization (WHO), there are approximately 285 million individuals around the world currently living with partial or total blindness. These visually impaired individuals face numerous obstacles which they must overcome as they go about their lives with mobility being one of the most difficult and dangerous challenges. This smart cane, named Walking Wise, will combine the functionalities of a camera sensor and image recognition software as well as an ultrasonic sensor to detect obstacles in the user's immediate surroundings and return measured information via mixed feedback system consisting of speakers and vibrating motors. Walking Wise is designed to be portable, environmentally friendly, and cost efficient to ensure this product can impact as many lives as possible. To test the functionality of this device, a volunteer is placed in an unknown and controlled environment with a Walking Wise prototype. The controlled environment contains various obstacles that fall into this area of interest. If the volunteer can navigate the course blindfolded, the goal is achieved, and the project is successful.

Keywords: Image Recognition, 3D Modeling, FEA

INTRODUCTION

According to World Health Organization (WHO), there are approximately 285 million individuals globally suffering from visual impairment, with 39 million being completely blind [1]. This growing population relies on outdated technology (see Fig. 1) to provide mobility in today's world. The probing cane is nothing more than a collapsible rod that provides no output other than improving the range of the user's sense of touch. The blind rely on others around them to assist in their navigation of crosswalks and traffic lights. The probing cane is unable to detect the presence of low hanging objects. Branches, fire escapes and low ceilings obstruct the forward path without a ground contact point. Consequently, the probing cane is unable to help the user detect said objects, leaving the individual vulnerable. These issues create a need for an improved probing cane, capable of detecting obstacles and environmental changes regardless of the presence of a ground touch point. A cane equipped with innovative sensors will be able to detect oncoming obstacles while informing the user upon approach. Furthermore, the sensors can detect the different outputs of crosswalk signals, allowing independence when crossing intersections. The advance sensor probing cane will provide increased mobility of the user.

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Figure 1. Probing Cane [17]

OBJECTIVE

The objective of this project is to create an easy to use device, capable of detecting a wide range of obstacles in hopes of improving the mobility of the visually impaired community. The probing cane is outfitted with an onboard camera sensor and ultrasonic sensor which will detect environmental changes and obstacles around the user. Using data gathered from the camera and ultrasonic sensors, a feedback system will relay the presence of obstacles and their nature. The device will be user-friendly to accommodate all ages, with controls for feedback intensity. Finally, the device will be collapsible, lightweight and rechargeable to improve portability.

BACKGROUND RESEARCH

The visually impaired community relies on a variety of sources for aid as they travel. Recently, particular researchers and companies have begun working to improve the probing cane. The reoccurring trend is to incorporate ultrasonic sensors into the probing cane in one of two manners.

The first innovation is an add-on device that attaches to a probing cane in order to add sensors to existing canes. One of the most popular versions is the SmartCane model, developed by IIT Delhi, Saksham and Phoenix Medical Systems, featuring two ultrasonic sensors which detect objects that lack ground touch points [2]. The lower sensor detects low hanging objects at knee height while the upper sensor detects objects from knee height to head height.

The second innovation is a custom-built probing cane featuring ultrasonic sensors and a feedback system. The most prominent example is the UltraCane created by a company of the same name [3]. Like the SmartCane, the UltraCane has two built in ultrasonic sensors. The lower sensor detects all objects on the floor within a 3-meter range while the upper sensor detects objects within a 1.5-meter range between chest and head height. The two buttons vibrate in order to notify the patient of the distance and direction of the object or obstacle.

Figure 2. UltraCane [18]

HOW IT WORKS

The functionality of the Walking Wise will increase user mobility by detecting obstacles and then relaying the data in a simplified manner. For example, in Fig. 3, the probing cane will detect the crosswalk and crosswalk sign and then alert the user through voice commands and vibration feedback if it is safe to cross by detecting the walk sign signal. Upon approach of any obstacle in the user's path, the vibration will notify the user. As the user gets closer to the obstacle the vibration will increase in frequency.

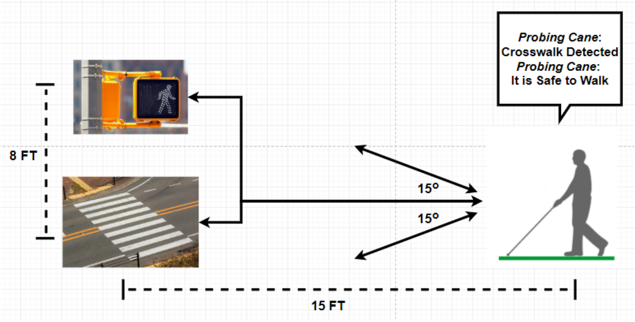


Figure 3. Crosswalk Diagram

MARKET REQUIREMENTS

There are five major marketing requirements that must be fulfilled to satisfy project completion; safety, portability, longevity, user friendly and economy. Safety–Walking Wise must be able to accurately detect staircases, overhanging obstacles and crosswalk signals. Walking Wise, built upon current aids and new technology, will replace the older modeled mobility aids. Portability–Walking Wise must be easily transported, with product weight as low as possible. Longevity–Walking Wise must be constructed to last a lifetime, with a minimum operating time of three hours before a recharge is required. User-friendly–Users must be able to effectively operate Walking Wise with minimal training required. Economy–Walking Wise should be offered at a relatively low price to cater to individuals with low income or government assistance.

CONTROL SYSTEM

Fig. 4 shows a basic look of out device's control system. Controls Engineer is used in mostly in every aspect of engineering. It is very important to be able to determine the system's controller, processor, and feedback system. The controller could act as a PID system (Proportional Integral and Derivative system). The controller could result in a permutation of the PID system such as: 3P3 = 6 → P, I, D, PI, PD, or PID systems. In other words, generally, a PID controller is an instrument used in industrial control applications to regulate temperature, flow, pressure, speed and other process variables. PID (proportional integral derivative) controllers use a control loop feedback mechanism to control process variables and are the most accurate and stable controller.

Relating to Walking Wise, the controller being used is Raspberry Pi 3B+ model, the processors are the vibration and sound mechanism, and the feedback systems are the sensors and camera. To be more detailed, the cane works in the following way:

1. The cane detected the objects (Crosswalk, Stop Signal, or Walking Signal) using image recognition and the camera.
2. Once the object is detected by the camera, the signal gets processed by the controller to determine which of the three objects it's detecting.
3. The controller then sends the output to the processing units.
4. After the object is detected and the pi processes it, an output is set and used to notify the user. These outputs are specific vibrations and sounds for each possible object detected.
5. While the vibrations and sounds are produced, the feedback system sends a new signal for the camera to start detecting objects again.
6. The process keeps running depending on the feedback system.

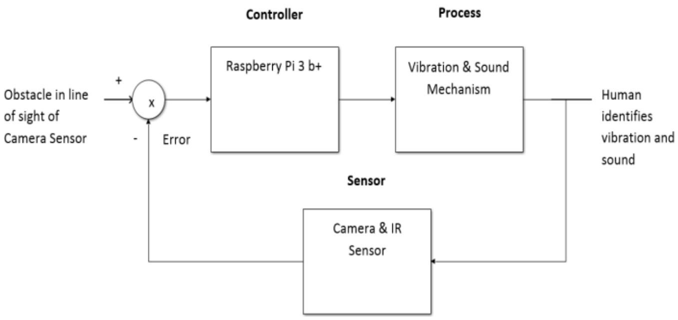
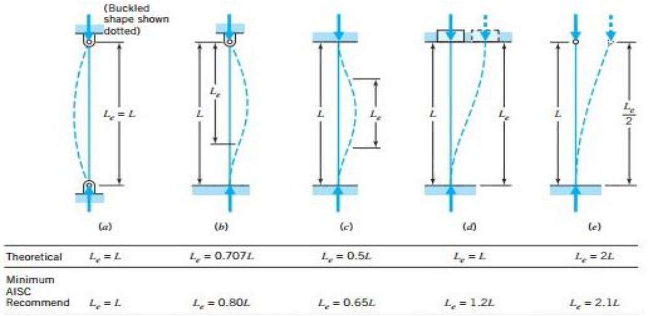


Figure 4. Control System

MECHANICAL SYSTEM

The probing cane is expected to undergo numerous points of loading during use. To create a strong and durable design, the mechanical system will be explored and analysed. The mechanical system is based on column and bending loading. Column loading is analysed using Euler's loading while bending loading is analysed using bending moment equations. By utilizing two different methods, a strong and durable design is made to withstand the punishment of loading. Fig. 5 (Euler's Loadings) and Fig. 6 (Bending Moment) show a description of the two different loadings that the probing cane will undergo during use along with the formulae on how to evaluate the two different loads, Equation 1 and 2, respectively.



	(a)	(b)	(c)	(d)	(e)
Theoretical	$L_e = L$	$L_e = 0.707L$	$L_e = 0.5L$	$L_e = L$	$L_e = 2L$
Minimum AISC Recommend	$L_e = L$	$L_e = 0.80L$	$L_e = 0.65L$	$L_e = 1.2L$	$L_e = 2.1L$

Figure 5. Mechanical System

Equations for the mechanical strength of the Cane are as follows:

$$P_E = \frac{\pi^2 E * I}{L^2} \tag{1}$$

P_E = Euler's Load
E = Elastic Modulus
I = Moment of Inertia
L= Length (Refer to Chart)

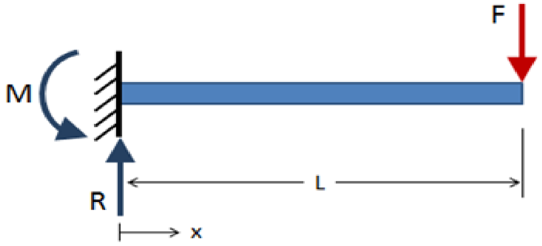


Figure 6. Bending Moment

$$\sigma = \frac{My}{I} \tag{2}$$

σ = Stress
M = Bending moment
y = Vertical distance away from neutral axis
I = Moment of Inertia

Using (1) and (2), calculations are made to better understand the amount of loading required for the probing cane to regain its structural integrity during use. The amount of loading applied to the probing cane should result in elastic deformation. In the elastic deformation region, the probing cane will be able to bend and buckle without destroying the true structural strength of the material.

ENGINEERING REQUIREMENTS

Cane Dimensions: Total length: 1200 mm – 1500 mm, folded length: 250 mm – 360 mm, weight: 1300g.

The probing cane will be 3D printed as a prototype. CATIA (Computer Aided Three-Dimensional Interactive Application) software is used to create the first prototype design of the probing cane. Fig. 7 represents the 3D Model design for the Smart Cane: Walking Wise. The prototype is composed from three main components; handle, housing case, and probing shaft that will utilize different functions.

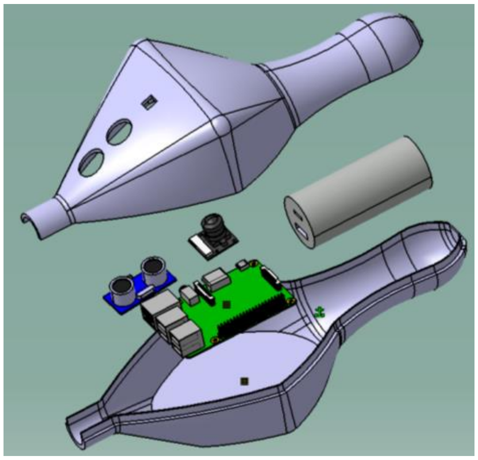


Figure 7. Prototype 1

A. Handle Design: Prototype 1

The cylindrical and ergonomic shape of the handle makes the grasp of the cane easy and comfortable. The handle is connected to a hollowed shell. The hollowed shell will serve as a location to house the components such as a battery source. This will reduce weight and material used. The battery source is stored in the shell and connected to the Raspberry Pi microcontroller via an extended micro-USB connection. The handle is the primary location of the vibrating feedback mechanism. The handle will vibrate when the ultrasonic sensor senses an object or obstacle at a distance. The vibrating motors will be stored inside the handle. The placement of the vibrating motors will optimize the vibrating feedback system and the user will easily feel the vibration. Since the probing cane is a uniform design, the vibration will travel throughout the whole design. To reduce the amount of vibration shared onto the other components of the design, an anti-vibration material will be used on that site. The anti-vibrating material will be used as a shock-absorbent to prevent the electrical components from moving and prevent the wiring from disconnecting. The anti-vibrating material as shown in Fig. 8 is designed in such a way to locate the vibration on the handle and insulate the components located in the housing case.

Figure 8. Anti-vibrating material [19]

B. Housing Design: Prototype 1

The housing case stores all the electrical components such as the Raspberry Pi microcontroller, Raspberry Camera, Ultrasonic sensor, and Mini Metal Speaker. The design and placement of the components are made to use as minimal a surface area as possible. Utilizing minimal surface area will reduce the size and weight of the probing cane. It will provide better performance and functionality. It is also cost effective as it minimizes the amount of 3D material needed to print the design. Fig. 9 shows the electrical components stored in the housing case.

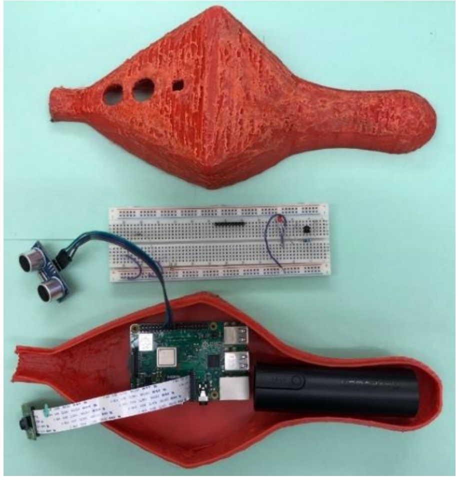


Figure 9. Housing Case with components

C. Probing Shaft Design: Prototype 1

The probing shaft will be designed to withstand the stress of probing the ground. A finite element analysis is conducted to provide data of the structural integrity of the probing cane under loading. The loading that the probing cane is expected to undergo will be buckling stress and bending stress. Buckling loading is explored using Euler's equation while bending loading is explored using the bending equation. Calculations are made using the best suited material for the probing cane. The material is decided based on price and structural strength.

D. FEA Analysis: Prototype 1

Using CATIA software, a FEA (Finite Element Analysis) was conducted on the first prototype. The finite element analysis yielded data that suggests the design must be redesigned. The structural integrity is questioned in the results. There were many location points where the design failed under minimal loading shown in Fig. 10. As for project purposes, prototype 1 will be used to complete the project.

In Fig. 10, a load of 100N was loaded on the perpendicular to the handle. This load represents a bending deformation that the handle will undergo during daily use.

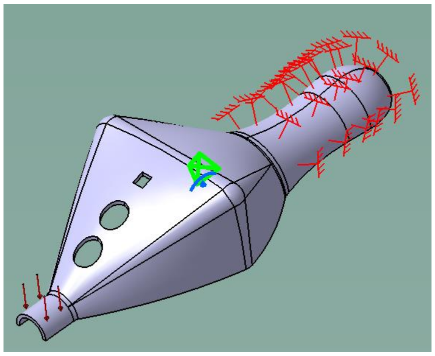


Figure 10. Loading on Prototype 1

Fig. 11 shows the 3D model major failure location points. The probing cane fails at areas colored in green, yellow and red. Most of the critical failure points are located on the handle connection of the housing casing. This component will experience failure if these issues are not addressed. It is safe to assume that failure occurs due to the drastic change of cross-sectional area which is a key concept in solving the problem. The problem can be fixed by gradually increasing the cross-sectional area to prevent structural failure. In the future redesign, the handle should gradually connect to the housing case in a cone shape design. This will also reduce the amount of sharp edges that can lead to failure. By having a cone shape design throughout the handle to the probing shaft, the failure locations can be dismissed thus creating a stronger, more durable probing cane.

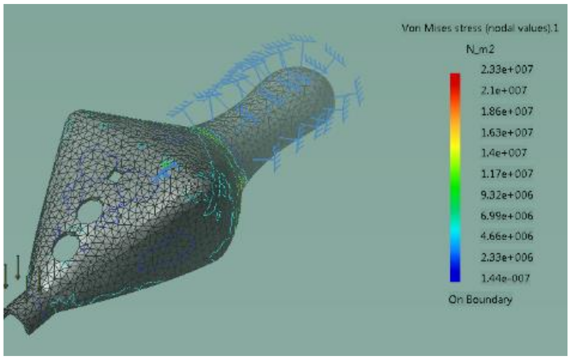


Figure 11. Failure on Prototype 1

E. Electronics Packaging: Prototype 1

Fig. 12 represents the layout of the electrical components that are stored in the housing case of the design. The list of the components are shown in Table 1.

Table 1.

Component’s Name	Quantity
Raspberry Pi 3 Model B+	1
Ultrasonic Sensor HC-SR04	1
Vibrating Motors	1
Piezo Speaker	1
Breadboard	2
1000 Ω Resistor	3
470 Ω Resistor	2
Diode Rectifier 1A 50V	2
Transistor NPN B0337	2
Connection Wires	25

In the design, the breadboard is located directly on top of the Raspberry Pi to reduce area consumption of the housing case. The power source is connected via micro USB to a battery source located in the handle shell. The sensor components are in specified areas of the housing case to improve detection of obstacles and view path. The components are mounted and cased in a thin layer of anti-vibrating material (Fig. 7). The anti-vibrating material’s purpose is to negate the minor vibration caused by the vibrating motors. By reducing the vibration of the main components, this may prevent damage and disconnection of wires while the probing cane is in use.

The schematic shown in Fig. 12 describes the layout of all the components connected by a breadboard to prove functionality of the probing cane. The components are elevated using pillars in the design to prevent rubbing or touching of the 3D printed design. This also keeps the components stable in the housing case. The Raspberry Pi Camera is connected to the camera port on the Raspberry Pi microcontroller. The Ultrasonic sensor is connected in series with a 1000 Ohm and a 470 Ohm Resistors via breadboard and pin ports on the Raspberry Pi microcontroller. The speaker is connected in series with a Transistor - NPN B0337 via breadboard and pin ports on Raspberry Pi microcontroller. The vibrating motors are connected in series with a Diode Rectifier via breadboard and pin ports on the Raspberry Pi microcontroller.

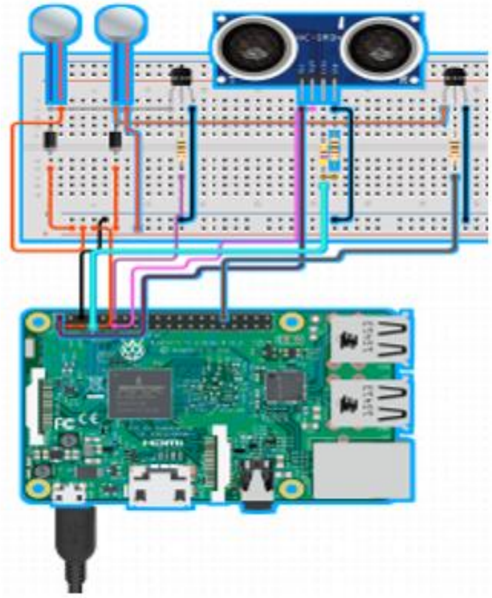


Figure 12. Electrical Schematic

IMAGING RECOGNITION

As technology continually grows, it is woven further and further into our society. This rapid rise has resulted in drastic computer Artificial Intelligence (AI) developments which in turn have led to the establishment of Computer Vision (CV). Computer Vision is a field of computer science that allows computers to detect, identify and process their environment in a way similar to humans [4]. As development of CV expanded, it was applied to the field of image recognition/object detection, the process of identifying real-world objects in images or video feeds. Object detection has already found its way into consumers’ lives in the forms of surveillance systems, facial recognition and advanced driver assistance systems (ADAS) [5]. Walking Wise expands the use of CV to a more humanitarian field by utilizing object detection to grant visually impaired individuals a better understanding of their surroundings.

A. TensorFlow

Machine learning is a complex discipline. But implementing machine learning models is far less daunting and difficult than it used to be, thanks to machine learning frameworks—such as Google’s TensorFlow—that ease the process of acquiring data, training models, serving predictions, and refining future results [6].

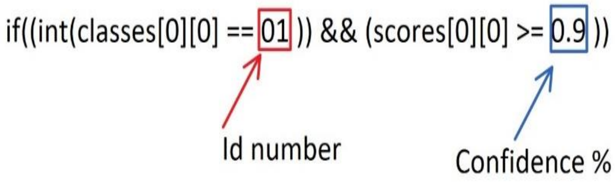
Created by the Google Brain team, TensorFlow is an open source library for numerical computation and large-scale machine learning. TensorFlow bundles together a slew of machine learning and deep learning (aka neural networking) models and algorithms and makes them useful by way of a common metaphor. It uses Python to provide a convenient front-end API for building applications with the framework [6].

TensorFlow can train and run deep neural networks for handwritten digit classification, image recognition, word embeddings, recurrent neural networks, sequence-to-sequence models for machine translation, natural language processing, and PDE (partial differential equation) based simulations [6].

B. Implementation

Walking Wise will combine a Raspberry Pi microcomputer, a high-quality camera and a trained object detection model to create an intelligent system capable of detecting and categorizing objects/obstacles in its environment. For the purpose of this project, the focus is on the following three essential tasks; detecting when a user has encountered a crosswalk, determining the status of the pedestrian signal, followed by relaying this information to the user through a mixed feedback system consisting of vibration and sound. The model will be trained using the ssd_mobilenet TensorFlow model provided by Google as the base of a custom trained object detection model [7]. There are four main steps that make up the training process: compiling TensorFlow and the required packages, gathering and labeling sample images as raw data, conducting training on a host PC and finally testing and troubleshooting the model.

Fig. 13 highlights a key section of the object detection script. The key processes within that snippet are the classes and scores functions which are responsible for classifying each object detected and producing its confidence factor respectively. Using these classifications and their confidence factors, we can then implement a unique feedback system for each class detected of a certain confidence factor. Fig. 14 shows a working prototype of our object detection model being used to detect our objects of interest. As shown in the figure, we are comfortably detecting our objects of interest and are achieving high confidence factors.



```
if((int(classes[0][0] == 01 )) && (scores[0][0] >= 0.9 ))
```

Figure 13. Image Recognition Code

Walking Wise will require no user input as detection and feedback are handled by the device itself. Walking Wise will implement a technique called Edge Computing where all computing, raw data collection, analysis of data, and feedback, are completed on site eliminating the need for cloud servers [8]. This will significantly reduce latency and allow for real-time processing and feedback of data. Through the combination of our Raspberry Pi 3b+, a Raspberry Pi Camera, and a well-trained object detection model, Walking Wise will gift the visually impaired community greater independence.

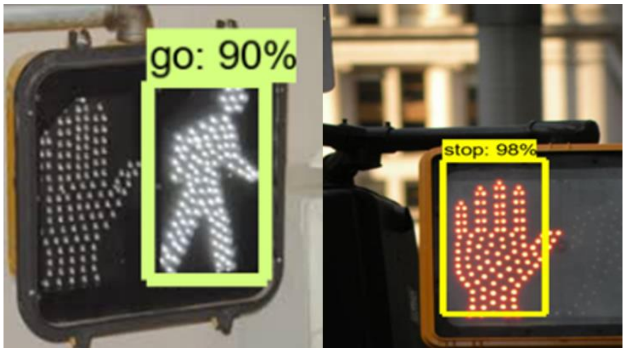


Figure 14. Imagine Recognition (Sign)

C. Working Principle

The basic working principle of this device is as follows: Raw data is collected by the device in the form of a live video feed from the camera. The object detection model continuously scans and analyzes the data, searching for objects it is trained to detect. When a detection of a high confidence factor is reached (the model outputs a confidence factor which is a percentage of how accurate the model thinks its detection is), this information will then be sent to the feedback system. The user will then receive feedback from the device in the form of speech, informing the user to the nature of the obstacle and what actions may be taken.

D. Movidius Neural Compute Stick

The performance of the imaging system is boosted through the addition of Intel's Movidius Neural Compute Stick (NCS) [9]. The NCS is a small deep learning device that allows AI programming to be done on the edge. It is powered by Intel's Movidius Vision Processing Unit (VPU) that allows developers to profile, tune, and deploy convolutional neural networks (CNN) and deep neural networks (DNN) for low-power applications that require real-time inferencing. This VPU will drastically improve the frame rate (fps) of the device, reducing latency and bring Walking Wise close to real-time detection. The device can be seen in Fig. 15.

Figure 15. Movidius Neural Compute Stick [20]

Ultrasonic Sensor

An Ultrasonic sensor is a device that can measure the distance to an object by using sound waves. It measures distance by sending out a sound wave at a specific frequency and listening for that sound wave to bounce back. By recording the elapsed time between the sound wave being generated and the sound wave bouncing back, it is possible to calculate the distance between the sonar sensor and the object [10].

Typical characteristics of an ultrasonic sensor includes:

- Detect transparent objects: since ultrasonic waves can reflect off a glass or liquid surface and return to the sensor, even transparent targets can be detected.
- Dust resistance: ultrasonic detection is typically not affected by an accumulation of dust or dirt.
- Detect complex shapes: ultrasonic detection is possible on objects with rough edges and for targets such as mesh trays or springs.

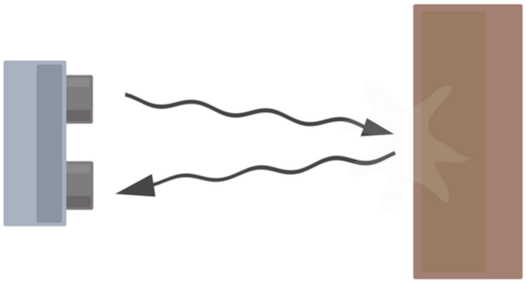
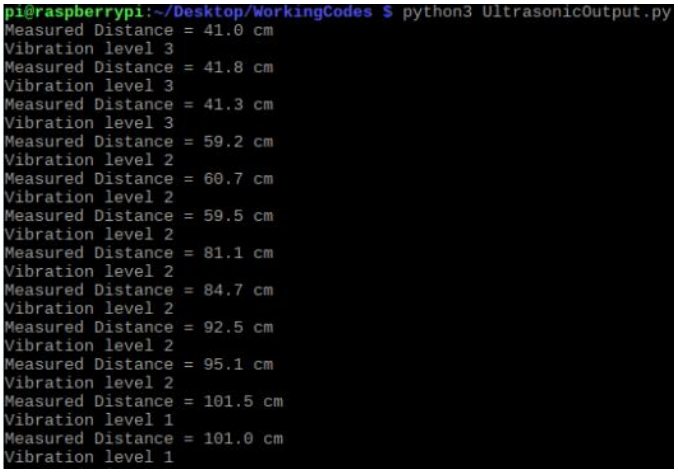


Figure 16. diagram of ultrasonic sensor operation [21]

A. Implementation

For our purpose, the HC-SR04 will be used to detect overhanging objects within the users' immediate path. It will cover a range from the users' navel (belly button) to an area above the users' head depending on their height. If an object is detected within range, a signal will be sent to the vibrating motors alerting the user of the potential danger. Doing this allows Walking Wise to offer more protection to its users' that is beyond the limitations of the traditional probing cane.

When the sensor is operational, and an object is within its detection range it will start to relay that information back to the Raspberry Pi and the distance of that object will then be processed. For increased functionality, we opted for a variable feedback system depending on what is being read from the sensor. This was done so that the user can have a better understanding of what the vibrations mean and where the potential hazard might be located. If the object is located within 50cm above where the sensor is located, vibration feedback 3 is initialized and a vibration feedback is felt by the user. If the object is judged to be located 51-99cm above where the sensor is located and within its limitations, vibration feedback 2 is initialized. If the object is 100-120cm above where the sensor is located and within the sensor limitations, vibration feedback 3 is initialized. This process is continuously looped so that the sensor is operational and reading distances once it is powered.



```
pi@raspberrypi:~/Desktop/WorkingCodes $ python3 UltrasonicOutput.py
Measured Distance = 41.0 cm
Vibration level 3
Measured Distance = 41.8 cm
Vibration level 3
Measured Distance = 41.3 cm
Vibration level 3
Measured Distance = 59.2 cm
Vibration level 2
Measured Distance = 60.7 cm
Vibration level 2
Measured Distance = 59.5 cm
Vibration level 2
Measured Distance = 81.1 cm
Vibration level 2
Measured Distance = 84.7 cm
Vibration level 2
Measured Distance = 92.5 cm
Vibration level 2
Measured Distance = 95.1 cm
Vibration level 2
Measured Distance = 101.5 cm
Vibration level 1
Measured Distance = 101.0 cm
Vibration level 1
```

Figure 17. Ultrasonic Code II

Components

Raspberry Pi 3 – Model B+ [11]:
Product dimensions: 87.0 mm x 58.5 mm x 18.0 mm, product weight: 49.7 g, processor: Cortex-A53 64-bit SoC @ 1.4GHz. Memory: 1GB SDRAM, connectivity: USB 2.0 ports, access: 40-pin GPIO header, video: MIPI CSI camera port, input power: 5V/2.5A DC via micro USB connector, output power: 5V/3.3V DC via GPIO header.

Figure 18. Raspberry Pi [22]

The functionality of the Raspberry Pi is to serve as the brain for this device and perform all computations.

Raspberry Pi Camera [12]:
Product Dimensions: 17 mm x 2.5 mm x 2 mm, product weight: 5g. High definition 5MP camera module. Field of view: 65 degrees

Figure 19. Raspberry Pi Camera [23]

The Raspberry Pi Camera will serve as the input sensor for object detection.

HC-SR04 Ultrasonic Sonar Distance Sensor [13]:
Input Voltage: DC 5V, power consumption: 15mA, ultrasonic frequency: 40 KHz, measuring angle: 15º, trigger input signal: 10uS high pulse, sensor dimensions (excluding header): 45.5 x 20 x 15.5mm, weight: 8.7g.

Figure 20. Ultrasonic Sensor [24]

The functionality of the Ultrasonic sensor is to detect distances of objects and relay data to the Raspberry Pi.

Vibrating Mini Motor Disc [14]:
Dimensions: 10 mm diameter, 2.7 mm thick, voltage: 2V - 5V, current draw: 40mA - 100mA, RPM: 11000 at 5V, weight: 0.9 gram.

Figure 21. Vibrating Motors [25]

The functionality of the vibrating motors is to provide vibration feedback to the user.

Stereo Enclosed Speakers [15]:
Dimensions: 30 mm x 70 mm x 17 mm, weight: 50g, power: 3W, impedance: 4ohm.

Figure 22. Speaker [26]

The functionality of the speaker is to provide audio feedback to the user.

Power Supply [16]:
Dimensions: 33 mm x 107 mm, capacity: 5000mAh, output: 5V/2.4A, weight: 181g.

Figure 23. Battery [27]

The functionality of the battery is to power the Raspberry Pi.

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