International Journal of Scientific Research in Science, Engineering and Technology

Print ISSN - 2395-1990
Online ISSN : 2394-4099

OPEN ACCESS

Available Online at :www.ijsrset.com
doi : https://doi.org/10.32628/IJSRSET2411434

Navigation Aid for Visually Impaired Persons using Vibration Haptics on a Jacket-cum-Headband Setup

Aditya Iyer
The International School, Bangalore, Karnataka, India

ARTICLEINFO

Article History:

Accepted: 15 Oct 2024
Published: 30 Oct 2024

Publication Issue :
Volume 11, Issue 5
Sept-Oct-2024

Page Number :
306-313

ABSTRACT

The device proposed here is a jacket-cum-headband device for mapping chaotic environments and communicating locations of obstacles to visually impaired persons. This project focuses on constructing a device which uses vibration as a haptic mode of communication to inform users on potential obstacles in their vicinity. This device is a low-cost solution for visually impaired persons to navigate within chaotic indoor environments such as houses, schools, or workplaces. The device is manufactured using 3D printed parts and readily available electronics, mounted onto articles of clothing for ease of use. The device is equipped with a Raspberry Pi 4B microcontroller, a USB colour camera, and 3 vibration-haptic modules embedded within a wearable shirt. The device uses Convolution Neural Networks (CNNs) and mathematical estimation formulas to detect obstacles in the user's proximity and determine their distance and direction from the user. The device communicates the locations of potentially hazardous obstacles to the user by inducing vibrations of varied intensity in the vibration-haptic modules. The device is tested on 4 different objects located in front of, to the left of, and to the right of the user, at distances between 1 metre and 6 metre.

Keywords : Navigation Aid, Raspberry Pi, CNN Algorithm, Object Detection, Visually Impaired

I. INTRODUCTION

India suffers a significant problem of visual impairment, with surveys estimating more than one-fourth of the population over the age of 50 to be visually impaired [1]. Data by the World Health Organisation (WHO) suggests a similar statistic that developing nations face a greater proportion of visual impairment [#]. Cataract is the leading cause of blindness in India, with around 90% being avoidable through surgical and interventionist means [2].

Research suggests that visually impaired persons find it difficult to navigate indoor environments due to many factors, which reduces their confidence in independent navigation [3]. Indoor environments may often contain unpredictable or potentially hazardous placements of objects requiring accurate circumventive navigation. To meet this requirement, visually impaired persons rely on assistive technologies. Advancement in this assistive technology build off the Blind Stick by adding functionalities through sensors and modules [4]. A comprehensive review of navigation systems identifies systems which combine RGB-D cameras and sensors as exciting technologies which improve perception, object manipulation, robustness, and safety [5]. Intelligent navigation systems must communicate information to the user. The mode of this communication defines a user's compatibility and comfort when using this device.

An existing device explores combining inputs from an RGB-D camera and sensors with force-haptic outputs, interfacing with the user through a wearable wristband device and aiding in indoor navigation [6]. This device uses stretching of fabric to induce small normal and tangential forces on the user's arm.

One device explores the usage of vibration-haptics of varied intensities, which provides a tactile feeling of vibration to the user [7]. This device explores users' sensitivities to different levels of vibration intensity, and it further explores users' specificity at identifying vibration patterns.

Another device, a handheld device with vibration-haptics, explores the usage of asymmetric vibrations to provide directional cues to the user [8]. This device allows directional information to be conveyed to the user, hence opening a new stream of communication that provides directional rather than magnitudinal information.

The device proposed here combines the concepts of vibration-haptic modules, RGB camera input, asymmetric directional cues, and varied vibration intensity. This device uses a USB colour camera mounted on a headband and 3 vibration-haptic modules embedded within a wearable shirt, both of which are controlled by a Raspberry Pi 4B. A YOLOv8 Convolution Neural Network (CNN) and mathematical estimation formulas are used to detect obstacles in the user's proximity and determine their distance and direction from the user. The locations of obstacles are communicated to the user through vibrations of varied intensity at different locations in the wearable shirt.

Objectives

The Navigation Aid device presented here acts as a vibration-haptic aid for visually impaired persons. It actively processes visual data from the mounted camera using machine learning models and communicates information of obstacle locations to the user using directional and varied intensity vibration-haptic feedback. The device has two objectives to fulfil, a primary and a secondary objective.

The primary objective of this device is to capture visual data from a built-in camera, to process this data in an environmental context using machine learning models and mathematical functions, and to rapidly inform the user about potentially hazardous obstacles through a novel haptic interface. This primary objective is concerned with the functionality of the device, in terms of its accuracy and speed of operation. The secondary objective of this device is to adapt itself to the user and the environment. This entails changing vibration intensities to suit the user, determining the priority by which obstacles and their locations are communicated, and optionally providing other communication modes such as, for example, sound. This secondary objective is concerned with the comfort of the user when using the device.

Construction

The Navigation Aid device consists of three parts: A) the headband, B) haptic-integrated shirt, and C) the electronics box.

The Headband is a 3D printed bracket clamp with a Hikvision DS-U02 colour camera. A clasp-hole on the back of the bracket connects to an elastic Velcro strap which is tied around the user's head. A USB-A cable connects camera to the Raspberry Pi 4B in the electronics box.

The Haptic-integrated Shirt is a tailored shirt with pockets sewn into the cloth at the back. Custom 3D printed Haptic Modules are inserted into these pockets. Each Haptic Module is placed in a separate pocket at different locations on the shirt. Positive (+7.4V) wires from each cluster are connected to their respective MOSFET Driver Module within the electronics box. Ground (GND) wires from all clusters connect to a common ground wire inside the electronics box.

The Electronics Box is a 3D printed box with a slidable top-lid. Screw-holes are present in the box's base to connect electronic components. Wider rectangular holes are made on the walls for cables and wires. The following electronics are placed within the box:

1.1) 1x 7.4V Lithium-Ion battery
1.2) 1x Raspberry Pi 4B with 8GB RAM
1.3) 4x HW042 MOSFET Driver Module
1.4) 1x on-off-on 3-way switch

Within the Electronics Box, a common ground (GND) wire is established between the battery's negative wire, the Raspberry Pi 4B's GND, each HW042's GND, and the negative wire of the barrel-plug socket for charging. The battery's positive wire is connected to the common terminal of the 3-way switch. One terminal of the switch is connected to the positive wire of the barrel-plug socket for charging. The other terminal of the 3-way switch is connected to the common power (+7.4V) wire. This wire is connected to the Raspberry Pi via a buck convertor, and to each HW042's voltage-in (VIN) socket.

Jumper cables are used to connect the Raspberry Pi 4B's General-Purpose Input / Output (GPIO) pins to their respective HW042's signal (SIG) pin.

Positive and Negative wires from the Haptic Modules are connected to V+ and V− pins respectively on their respective HW042. USB-A cable from the camera connects to a USB port on the Raspberry Pi 4B.

Table 1 lists all major hardware parts used to construct this device.

Table 1 : List of all major hardware items

#	Name of Hardware	Usage	Qty
1.	Hikvision DS-U02 colour camera	Capture the visual feed in front of user	x1
3.	Headband: bracket (3D printed) & Velcro strap	Mount camera in bracket & wear around user's head	x1
2.	10mm x 3mm coin-vibration motor	Generate vibration in haptic module	x6
4.	Haptic Module (3D printed)	Combine 2 coin-vibration motors	x3
5.	7.4V Lithium-Ion battery	Power the device	x1
6.	Barrel-plug socket	Charge the Li-Ion battery	x1
7.	Raspberry Pi 4B with 8GB RAM	Process video feed & power haptic	x1

		modules	
8.	HW042 MOSFET Driver Module	Provide power to haptic modules upon signal from Raspberry Pi 4B	x4
9.	3-way on-off-on switch	Switch between charging and powering device	x1
10.	Electronics Box (3D printed)	Hold electronic components & circuits	x1

Working Principles

Figure 1 is a block-diagram of the Navigation Aid device. This figure displays the inputs and outputs of the device.

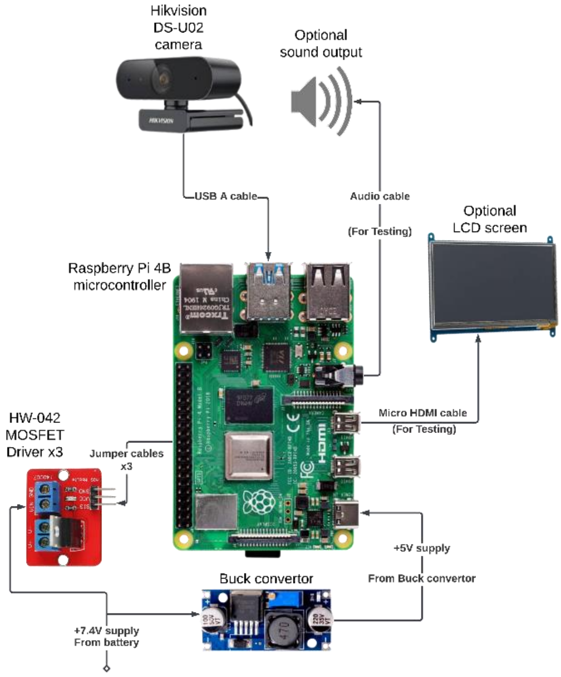

Figure 1 : Block Diagram

The Raspberry Pi 4B receives +5V power from a buck convertor, which is connected to the +7.4V battery. Video input is received from the colour camera, connected via a USB-A cable. The microcontroller uses the video input to produce PWM output for each haptic vibration module. GPIO pins on the microcontroller send signals to the HW-042 MOSFET drivers, which allow current to flow into the haptic modules.

An optional display output was used during testing to program and debug the microcontroller. An optional speaker was connected to the microcontroller through the audio jack for debugging.

The program run by the Raspberry Pi is displayed in the program flowchart in Figure 2.

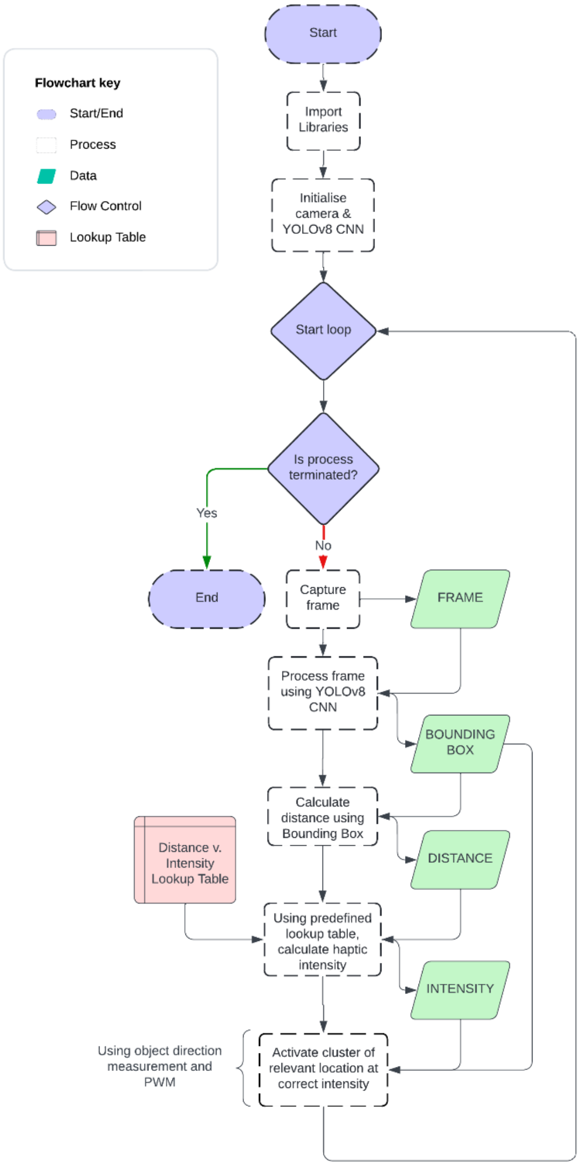

Figure 2 : Program flowchart

The program consists of a main loop, within which the algorithms are run sequentially. These algorithms use camera input, as seen in Figure 1, to provide vibration output of different intensities to the user.

Algorithms

There are 3 main algorithms being run during the main loop of the Navigation Aid device. The algorithms are run in same the sequential order in which they are described below.

YOLOv8 CNN Object Detection

The Navigation Aid device uses a YOLOv8 Convolution Neural Network (CNN) to detect common household objects within the frame of the camera.

A 2D Convolution is a mathematical function which accepts a 2D Array of values as input and returns a similar 2D Array as output. The value at some location (x, y) in the output array is a result of some mathematical functions on those values in the input array which have locations neighbouring (x, y).

A CNN consists of multiple convolution layers. The model used here takes a 224x224 image as input and uses convolution layers to determine the position and bounding-box region of certain common household objects as detected in the image.

For each detected image, the model outputs a class ID, confidence score, and bounding box. The detections with confidence score above the threshold (=0.5) are selected for use, while the others are discarded.

Distance Determination

Following Object Detection, the program uses a distance determination algorithm to convert a bounding box into a distance value. This algorithm uses the screen-space coordinates of the bounding box to determine the real-world distance between the object and the camera. The distance determination algorithm is based on a trigonometric formula, as follows.

The width of the bounding box is divided by the frame's total width. This fraction represents what horizontal portion of the frame is taken up by the detected object. This fraction is multiplied by the object's known width. By doing so, the width of an imaginary 2D plane is captured. This imaginary plane cuts the detected object in 3D space. This plane is perpendicular to the camera and at some distance from the camera's lens.

Half of the width of this imaginary 2D plane is multiplied by the cotangent of half the camera's horizontal focal angle. This calculated value represents the distance of the imaginary 2D plane from the camera's lens. This is the desired real-world distance value which is used by the Navigation Aid device.

Location-based Signalling

The real-world distance between the user and the object is communicated to the user through the signalling algorithm. This algorithm determines the intensity of vibration for each haptic cluster.

Based on the lateral position of the object with respect to the user (to the left, to the right, or forward), the algorithm triggers the respective haptic module located at different positions within the shirt via the HW042. The respective GPIO pin is activated using pulse width modulation (PWM).

PWM is a signalling method where the pin is repeatedly set to HIGH (+3.3V) and LOW (+0V) alternatively for different periods of time. The full pulse time is defined as the total time the pin is set to HIGH plus the time it is set to LOW. The duty cycle is defined as the time the pulse is HIGH divided by the full pulse time. By adjusting the duty cycle, it is possible to adjust the total power which is permitted to flow through the MOSFET to the haptic modules. Hence the intensity of vibration can be controlled.

According to the distance calculated by the determination algorithm, the respective haptic cluster is operated at different duty cycles. For distances less than 1.5-metre, the duty cycle is set to 100%, whereas for distances between 6- and 10-metre, it is set to only 25%.

Using pulse width modulation, this haptic cluster is operated at different duty cycles (pulse lengths) depending on certain arbitrarily chosen distance thresholds. For example, objects closer than 1.5 metres trigger a 100% duty cycle, whereas those between 6 to 10 metres trigger only 25%.

The signalling algorithm uses a lookup table similar to Table 2 to determine the duty cycle needed to operate the GPIO pin.

Table 2 : Lookup table for duty cycles by distance

Distance (in metre)	**Duty cycle**
<1.5m	100%
1.5m to 3m	75%
3m to 6m	50%
6m to 10m	25%
>10m	0%

II. RESULTS & DISCUSSION

This device was tested using 4 household objects: chair, table, bicycle, and football. The device was worn by a user standing at one side of the room. The objects were placed on the floor at different locations. No other objects were placed on the floor. The wall opposite to the user had two windows with closed curtains.

Objects were placed at 4 distances to cover all duty cycle intensities: 1, 2.5, 4.5, and 6 metre. Each object was tested 6 times: thrice to the left, thrice to the right, and thrice forward. This gave 9 tests upon which detection accuracy was measured.

Table 3 shows the accuracy of classifying objects based on the number of tests passed, the average confidence score of correct classifications, and the root-mean-squared error (RMSE) in distance measurement.

Table 3 : Results of field testing

Metric	Object	1 metre	2.5 metre	4.5 metre	6 metre
Accuracy	Chair	9/9	9/9	9/9	9/9
Average Confidence		0.952953	0.952239	0.920475	0.887591
RMSE Distance		9.43 cm	21.3 cm	42.1 cm	58.2 cm
Accuracy	Table	7/7	9/9	9/9	9/9
Average Confidence		0.931578	0.842078	0.818722	0.798720
RMSE Distance		10.1 cm	26.8 cm	41.2 cm	46.2 cm
Accuracy	Bicycle	7/7	9/9	8/9	6/9
Average Confidence		0.779563	0.666594	0.599253	0.521381
RMSE Distance		10.8 cm	30.5 cm	61.3 cm	92.2 cm
Accuracy	Football	9/9	9/9	9/9	5/9
Average Confidence		0.91796	0.882100	0.830735	0.555562
RMSE Distance		9.17 cm	13.2 cm	38.9 cm	104 cm

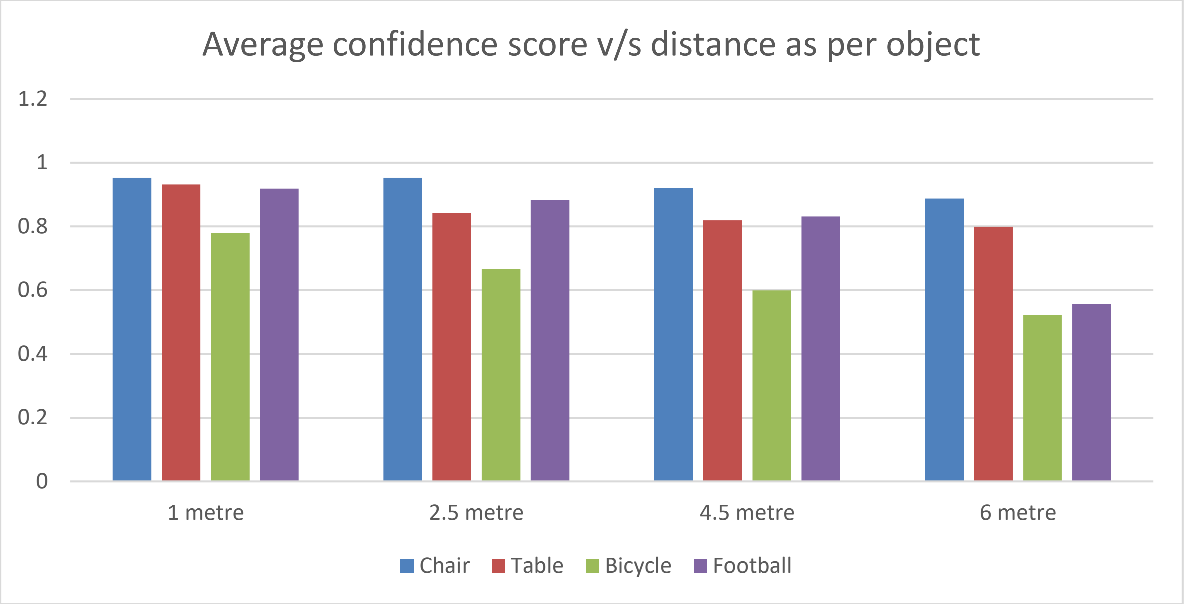

Figure 3 : Average confidence score v/s actual distance as per object

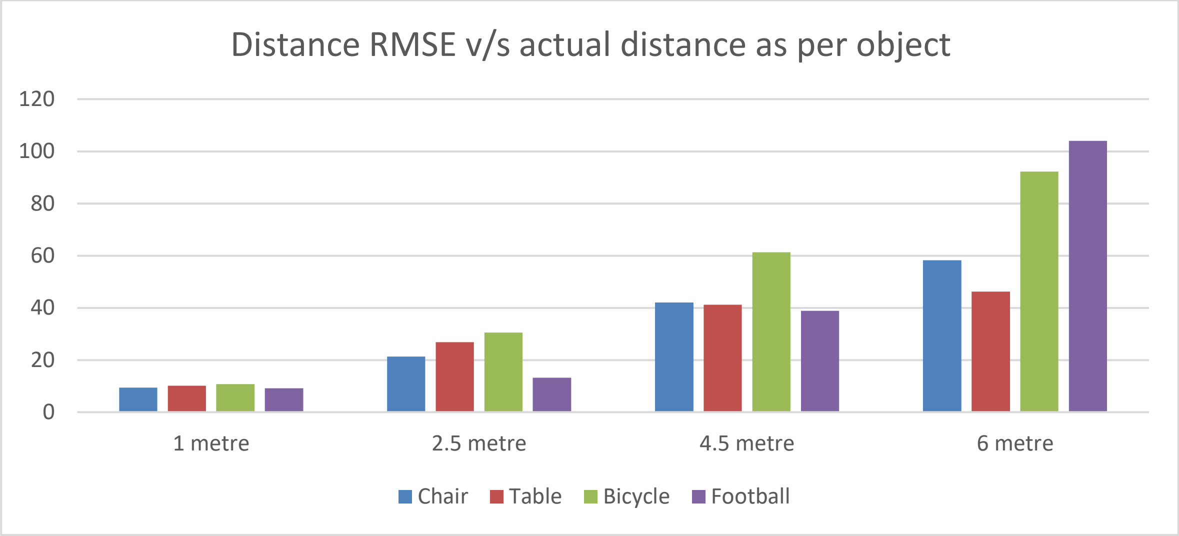

Figure 4 : Distance RMSE v/s actual distance as per object

Table 3 shows that the device makes correct predictions more that 50% of the time for objects within 6 metre, and more than 90% for objects within 4.5 metre.

Figure 1 shows high average confidence for chair, table, and football up to 4.5 metres, with bicycle's confidence scores being slightly lower yet still above the threshold. Confidence scores fall as distance increases, yet the scores are still reliable within the device's range. For indoor environments which are usually less than 6 metres, this device can make accurate detections.

Figure 2 shows that this device makes accurate distance measurements within its operational range. Distance determination for both furniture items has around 10% RMSE. For the football and the bicycle, which are more complex with more colours and shapes, distance determination has an RMSE of around 15%. In both cases, this error margin is acceptable for indoor environments.

III. CONCLUSION

The proposed Navigation Aid device presents a novel solution to fulfil its primary and secondary objectives of assisting visually impaired persons in navigating complex indoor environments using vibration-haptic feedback. The algorithm for object detection covers many household and workplace objects which could be present around the operating conditions of this device. The distance determination algorithm accurately computes distances of the object within 15% of error. The location-based signalling algorithm communicates positions of obstacles to the user using multi-modal haptic feedback. This feedback communicates both distance and direction of the obstacle. By using this device, visually impaired persons become more comfortable in navigating indoor environments. Meanwhile, this device does not impinge on other senses such as sound, which allows the user to operate freely while using the device.

In conclusion, the accuracy and reliability of this vibration-haptic device allows its usage in many indoor environments which were previously hazardous or to the user. This helps users develop confidence in navigating unknown indoor environments, hence improving their quality of life and allowing them to engage in tasks which were difficult to complete earlier.

IV. REFERENCES

[1]. P. Vashist et al., “Blindness and visual impairment and their causes in India: Results of a nationally representative survey,” 2022, Accessed: Oct. 02, 2024. [Online]. Available: https://doi.org/10.1371/journal.pone.0271736

[2]. K. Gopal, S. Kumar, and O. Garg, “Senior care reforms in India: Reimagining the Senior care paradigm.,” 2023. Accessed: Oct. 02, 2024. [Online]. Available: https://doi.org/10.31219/osf.io/tnr98

[3]. W. Jeamwatthanachai, M. Wald, and G. Wills, “Indoor navigation by blind people: Behaviors and challenges in unfamiliar spaces and buildings,” British Journal of Visual Impairment, vol. 37, no. 2, pp. 140–153, May 2019, doi: 10.1177/0264619619833723.

[4]. V. Kunta, C. Tuniki, and U. Sairam, Multi-Functional Blind Stick for Visually Impaired People. IEEE, 2020.

[5]. M. H. Abidi, A. Noor Siddiquee, H. Alkhalefah, and V. Srivastava, “A comprehensive review of navigation systems for visually impaired individuals,” Jun. 15, 2024, Elsevier Ltd. doi: 10.1016/j.heliyon.2024.e31825.

[6]. F. Barontini, M. G. Catalano, L. Pallottino, B. Leporini, and M. Bianchi, “Integrating Wearable Haptics and Obstacle Avoidance for the Visually Impaired in Indoor Navigation: A User-Centered Approach,” IEEE Trans Haptics, vol. 14, no. 1, pp. 109–122, Jan. 2021, doi: 10.1109/TOH.2020.2996748.

[7]. S. Khusro, B. Shah, I. Khan, and S. Rahman, “Haptic Feedback to Assist Blind People in Indoor Environment Using Vibration Patterns,” Sensors, vol. 22, no. 1, Jan. 2022, doi: 10.3390/s22010361.

[8]. S. Dong, J. Gallagher, A. Jackson, and M. Levesley, “A Hand-Held Device Presenting Haptic Directional Cues for the Visually Impaired,” Sensors (Basel), vol. 23, no. 20, Oct. 2023, doi: 10.3390/s23208415.