How Can We Harness Technology to Help Enhance Inclusion For People With Visual Impairment in Urban Environments?

Jai Gupta

Step By Step School, Noida, India

Abstract

This paper explores various assistive technologies for the blind, from assistive feeding devices to facial and object detection software and smart walking sticks. We break down the complexities of software and hardware, such as You Only Look Once (YOLO) object detection algorithm combined with the exploration of different hardware setups to understand what configurations fit best. We learn that providing active feedback during assistive feeding through tactile and auditory cues can cause disruptance to users, hence opting for smarter ways of output is imperative. We also find that to build an effective and affordable solution we must pack our hardware in a compact and light manner. Any assistive technology that helps with navigation must be equipped with cameras and have software that predicts the nature of different objects and ultrasonic sensors to accurately gauge the distance of objects. While these features may be complimented by others, we find that in order to build an effective device it is likely that these two basic features are present. Along with an overview of each of these technologies and their workings, we discuss overarching themes and opportunities to improve the technologies themselves as well as their usage in the broader sphere of assistive technology.

Keywords: Assistive technologies, Internet-of-things

1. Introduction:

As our society continues to rapidly advance, one of the most significant challenges we face is the lack of inclusion. According to WHO 285 million people are blind or have amblyopia (a type of poor vision that usually happens in just 1 eye but less commonly in both eyes. It develops when there's a breakdown in how the brain and the eye work together, and the brain can't recognize the sight from 1 eye) around the world, with 246 million having major vision impairment. However assistive technology for the blind and its usage is still very limited in today's world, this is substantiated by this study which shows that only 14.53% of blind people have access to assistive tech. [1]

Numerous efforts have been made over the years, from assistive feeding devices and walking sticks for the blind to the implementation of tactile pathways for better navigation. However, we have yet to achieve a state of total inclusion, where every member of our society is able to perform any task in the same capacity without being dependent on any other person. People with limited eyesight are a prime example of this ongoing issue. With them facing issues in social situations when it comes to dining as current assistive feeding technologies are not well developed enough to facilitate them in a non-disruptive manner.

One of the most important components of the research was my visits to members of the blind community in New Delhi to gain a deeper understanding of the challenges that they have to face every day. Through these interviews, I found that members of the blind community have to overcome much more than I could have ever imagined. One major issue that they struggle with is navigation in crowded or novel areas. While they can move around with relative ease in environments where they have lived all their lives which is familiar to them, they often struggle in new places. Navigating unfamiliar and crowded areas can be very dangerous for them, as they can easily be taken advantage of or unknowingly wander into dangerous situations. This means that these people face not only problems that are not only physical but ones which are also psychological and social. The constant need to be cautious and the fear of potential dangers can be mentally exhausting. Additionally, the feeling of being marginalised or isolated is increased by the lack of inclusive infrastructure and services. To improve inclusion, we must address these issues comprehensively. This involves not only improving accessibility in a physical sense through better urban planning and assistive technologies but also promoting and creating a more inclusive society that understands and supports the needs of the blind community.

In this paper, we will first discuss the various types of technology available to help the blind to see how we can improve on existing technologies to increase inclusion in our society. We will then also examine my learnings from the interview I held with the students at the blind school in Amar Colony, New Delhi to see what their opinions are on current or developing technologies and finally we will explore my solution to this problem which has been plaguing our society for quite some time.

2. Literature Review

2. A. Assistive Feeding

There are certain challenges that exist with assistive feeding. The first is the very nature of food itself; food is non-rigid and deformable, therefore making it highly difficult to create a system that is able to safely and efficiently feed all users for all types of food. Also, eating is a social act, hence finding or creating a robot which is able to feed the differently abled and the blind in a manner that is non-disruptive to such social settings is also important but challenging.

In [2] The study investigates the factors influencing successful bite transfer in robotic assistive feeding, emphasizing that the ease of transfer is linked to the initial food acquisition strategy. The researchers developed a robotic feeding system incorporating skewering and transfer primitives, evaluating their success rates and ease of bite transfer through experiments and user studies. The findings highlight the importance of intelligent, food item-dependent strategies in improving bite acquisition and transfer success rates. Essentially they found a few to mimic human ways of feeding by observing the food, mouth and other cues to autonomously feed the user, they also created a new database of foods which can be fed most effectively using the new technology. Their feeding system uses a 6 DoFJACO arm mounted on a ROVI-powered wheelchair, they have 2 fingers on the robot to help pick food up, and various cameras to incorporate visual feedback along with torque sensors to improve safety.

The system described in [4] uses a complex hardware system to achieve its purpose. The hardware foundation is a KUKA omniRob platform with a DLR lightweight arm featuring seven degrees of freedom. A Schunk three-finger hand is attached to the arm for object grasping. A Kinect RGB-D sensor is utilized to monitor the entire scene, detecting the cup, the user’s mouth, and potential obstacles. User communication is facilitated by a Brain-Machine Interface (BMI) that extracts control signals from EEG data. This setup enables the system to autonomously detect the cup and the user’s mouth, plan the robot’s movements to target locations, and execute tasks. Additionally, the system’s compatibility with BMI control based on motor-imagery tasks allows users to send control signals to the robot, ensuring seamless interaction and task performance. The unique component of this system is the EEG data and its extraction which can make it such that a user can control the robot by themselves. The objective of this robot is to autonomously deliver a drink to the user’s mouth by identifying the 3D positions of the cup and the user’s mouth. They use a Kinect RGB-D sensor to observe the workspace and determine these positions, necessitating a calibration step to transform coordinates between the robot and camera systems. Cup detection employs a colour-based classifier on HSV-transformed images to identify and locate the cup. For mouth detection, they transform the image to grayscale and use a haar cascade classifier to detect the face, then estimate the mouth’s position based on facial proportions. To manage occlusions when the robot’s end-effector approaches, they calculate the mouth’s 3D position by defining a plane using three facial points (forehead, left cheek, right cheek) and adjusting for user-specific anatomical features. This method ensures accurate mouth tracking even during user movement. A similar method of mouth detection was also used in the first paper, however, this robot was able to extend on that technology and calculate the mouth's 3D position using more facial points, hence increasing accuracy.

A notable part of this paper is the EEG data collection and manipulation which, if enhanced, can have vast applications on such systems. Since voice commands are impractical while drinking, they attempt to utilize brain activity decoding to communicate with the robot. The way the system is supposed to work is that EEG recordings successfully detect changes in EEG signal components when users imagine different movements, and these responses can be trained for increased reliability over time. Initially, the user sends one start command, and the robot autonomously executes the task, which includes finding and grasping the cup, bringing the cup to a position in front of the user, moving the cup to the user's mouth, tilting the cup, bringing the cup back to an upright position, moving away from the user's face, and returning the cup to the table. Each step requires an explicit go-signal from the user. The current system uses a fixed tilting angle, allowing a fixed amount of liquid. This can be extended by decoding a cancel signal from the user, enabling more flexible control over the tilt angle and stopping the liquid intake.

The user sends commands by imagining finger-tapping movements of the right hand, causing a decrease in alpha and beta frequency power measured by an EEG recording cap. They use a dry-electrode EEG cap for ease of use and comfort, with data acquired from 32 electrodes sampled at 512 Hz. Signal processing, feature extraction, and decoding are performed in real-time in MATLAB using an artificial neural network (ANN). Communication between MATLAB and the robotic system is implemented via a unidirectional UDP network interface over the campus' wireless network. When the system detects consecutive finger-tapping imaginations for 3 seconds, a 'true' bit is sent to the robot, balancing safety and user satisfaction by minimizing false positives.

All in all, assistive feeding presents multifaceted challenges, with bite acquisition strategies significantly impacting the ease of bite transfer in each of the studies reviewed. Factors influencing this include the proximity of the food item to the mouth and personal preferences. In surveys and tests, participants noted difficulties in removing bites from the fork due to the curvature of fork tines, highlighting the importance of physical interactions between the fork, food, and mouth especially in the first study reviewed. There is a critical role of timing in food transfer. Along with this, the scope of these studies does not cover the complexities of social dining. Future improvements could include autonomous perception of diverse food items, automated categorization of manipulation primitives, and learning from demonstrations. One study had the limitation that mostly able-bodied people were testing out the device which would mean that in actual application there may be a slight difference in actual performance. Future research should extend to individuals with severe motor impairments, ensuring the system brings food close enough to touch the mouth.

2. B. Facial & Object Detection

In [5] it uses an AI system called YOLO (You Only Look Once) to tackle object recognition. The main idea of this system is to help blind people by detecting and recognising different objects in indoor environments. The paper discusses using a deep learning algorithm called YOLO, which is very fast and consists of multiple layers in a convolutional neural network (CNN). YOLO trains the CNN on a set of images for a specific application which can vary. In this research, the CNN was trained using images from the COCO dataset to help the blind.

Papers [6] and [7] speak extensively about the use of an AI technology called YOLO which can be extremely helpful in this field of automation. YOLO (You Only Look Once) works by finding objects in images but does it as one task rather than breaking it down like most other systems and algorithms. YOLO essentially breaks a picture or an image down into a bunch of small squares similar to a chess board and tries to predict what it is looking at in the image. The predictions include the position and nature of the object, the position is determined or depicted by placing a box around and the nature is done by identifying what kind of object it is looking at. Each grid square predicts a fixed number of boxes, and a box prediction includes the centre of the box, the size of the box, and the probability of an object being in that box. If an object is present, the probability is set to 1; if not, it's set to 0.

YOLO has many different advantages. One of the biggest points that separates it from competing systems is the fact that it looks at the image as one whole rather than many small pieces which allows it to have more context. It is extremely quick, being able to process many images in a single second, hence making it a viable tool to use even for videos and other larger applications. Other methods, usually look at parts of the image separately, which can lead to mistakes, especially with the background, which YOLO makes fewer errors with because it sees the whole image at once and is better at detecting objects in different types of images.

During training, YOLO learns by looking at many images and predicting the boxes around objects. During testing, YOLO applies what it learned to new images, predicting the locations and types of objects quickly and accurately. All in all, YOLO is a powerful and fast tool for detecting objects in images by looking at the entire image at once, making it more accurate and efficient than other methods.
This algorithm can be massively helpful if further developed and placed onto different devices allowing people with visual disability to be better integrated into society

Now to discuss the second paper, the system is called the ‘Third Eye’ and it is built to assist visually impaired individuals by creating a system which will help with obstacle detection, facial recognition, and auditory cues. The prototype, embedded in a box mimicking a human form, serves two primary functions.

The first function is to alert users to the direction of approaching or nearby objects. Third Eye employs four sonar sensors connected to an Arduino Uno, which detect obstacles in the front, rear, left, and right directions. It also has a speaker embedded in the system which provides auditory cues. For example, if the user approaches a wall within 150 centimetres, the system gives a sound cue indicating "front." As the user continues to approach, the system continues to give the warning, however, If the user changes direction, the system updates the cue to reflect the new relative position of the obstacle. This functionality extends the user's detection radius, providing a lot of time to avoid obstacles. No sound cue is given when the user is stationary in order to make sure that the system is not too overwhelming, however, in my opinion, the idea of giving an auditory cue in the first place may be troublesome as it can interfere with day to day commute and life of people with such disability using the device.

The second function is that of facial recognition. A camera within the system identifies faces and a speaker announces the name of the recognised individual. For example, when the user approaches a person named "Aryan," the system announces the name of said person. This feature enhances social interactions by allowing users to recognize individuals they are conversing with or passing by. No sound cue is given if the face is unrecognized or if it is the same as the last recognized face, this again reduces the fact that such a system will be cumbersome to handle however it does not alleviate the possible issues previously mentioned.

Overall, the Third Eye enhances the spatial awareness and social interaction capabilities of visually impaired users, providing timely auditory information about their surroundings and familiar faces.

There are some constraints with such systems however, for example, you can’t use a rudimentary system like this one in harsher environments. Also, the battery life and ability to detect faces are questionable since it is running on Raspberry Pi. It is also aesthetically unpleasant. If such a system is to see implementation at any point then it must be upgraded rigorously. It must be run with cameras on devices with higher processing power, we can also use more advanced code (like YOLO as previously discussed) to improve face and object detection. Along with this eliminating the cumbersome auditory cues with something like tactile or more subtle auditory cues is a must to be discussed and explored.

2. C. Smart Walking Sticks

One of the main problems that the blind face is that of navigation in novel areas. A smart way to tackle this problem is by building walking sticks which would help orient the users to their surroundings. If perfected such a solution can help integrate the blind into our society and make hundreds of urban areas accessible without any extra expenditure.

The system essentially checks for 2 things water and obstacles. It buzzes twice when it detects water, but only buzzes once when it detects an object, the idea is to notify the user of the surroundings using these two functions so that they are able to navigate using this system.

In [8] the paper talks about building a stick for the blind which would allow them to navigate in novel areas freely. The description of the hardware is very extensive. The proposed system consists of several components interfaced with a microcontroller, primarily the Arduino UNO, which is based on the ATmega328p. The Arduino UNO features 14 digital I/O pins (6 usable as PWM outputs), 6 analogue inputs, a 16MHz quartz crystal, a USB connection, a power jack, and an ICSP reset button. The system brings together key components such as ultrasonic sensors, which detect obstacles from ground level to head height (up to 400 cm) and send real-time data to the microcontroller. Additionally, a moisture sensor uses two wire probes to detect water on the ground by sensing the specific resistance of water. The RF transmitter and receiver facilitate wireless communication between components, while the LCD displays relevant information. The buzzer is activated by the microcontroller to alert the user of detected obstacles or water. Designed to assist the visually impaired in navigating both indoors and outdoors.

There are a few flaws with this system, including details on how the device interfaces with the user: the system might overwhelm the person holding the stick since there is no software mechanism to provide a significant buffer between different output buzz types. If the system sees more than one object at a time, then it might buzz several times which could confuse the user. This sort of system also does not detect the type of an object which could mean that such a device may actually make the surroundings more complicated than they were without the device. The next generation of this device may instead utilize a small speaker or Bluetooth-connected earbud that utilizes language to communicate the surroundings and relevant device output to the user. It could also opt for less disruptive methods which would include constant haptic feedback.

In [10], the proposed system is unique, although it uses navigation systems that have been previously explored, this system claims to do it in a manner that is more efficient than others, its extensive hardware helps with this. The system consists of four main modules: the PCB unit with an RFID sensor, an Android application for the visually impaired person, a server, and a method called ‘monitoring user's Android application’. The PCB unit, which is mounted on a cane, includes an 89c51 microcontroller, Bluetooth HC05, MAX232, ADC 0808, IR sensors, and an RFID sensor. The microcontroller controls these components, with IR sensors detecting obstacles by emitting and reflecting infrared rays. This data is transmitted to the microprocessor, which sends the information via Bluetooth to an Android application on the user's phone, providing vibration alerts and, contrary to the first paper’s device, utilizes speech output. RFID tags offer additional location information, read by the sensor and communicated to the user through speech output. The visually impaired person's Android application, configured by a relative or family member, synchronizes with the PCB unit via Bluetooth. It provides speech output for obstacle detection and RFID tags, along with vibration alerts. The server stores the user's location information, updated as the person moves, using a Glassfish open-source server for this purpose. The monitoring user's Android application allows relatives or family members to access the latest location of the blind person stored on the server. Together, these components form a system that enables visually impaired individuals to move independently from one place to another, ensuring safety and enhancing mobility. With the addition of person-to-person connections in the app, it further enhances social communications to friends and family.

There are a few flaws with this device as well, mainly the fact that it uses only IR sensors to do its object detection, due to this we will know nothing about the type of the object, rather we will only know about the position of the object hence it does not allow us to give accurate feedback to the user about their surroundings, however, the optional camera support does help with this.

In [9], the paper's main goal is to assist visually impaired people by developing smart walking shoes. It uses an ultrasonic sensor to detect obstructions within a configurable range of up to 2 meters and a moisture sensor to detect water, helping to avoid slippery surfaces. The shoe also detects stairs. Additionally, it can send notifications through an application in case a person gets hurt by pressing a button on the shoe.

The smart walking shoe integrates several components, including ultrasonic sensors, moisture sensors, a DF player, a speaker, and a WiFi module, all connected via wiring. The hardware consists of an Arduino Uno, ESP8266 WiFi Receiver, and various sensors and buttons. The Arduino IDE is used to upload code to the device, utilizing libraries such as 'NewPing.h', 'ESP8266Lib.h', and 'Blynk.h'. Pre-evaluation testing that they conducted showed that the shoe successfully assists in navigation and protects the user from falling or getting injured. It has sound alerts for obstacles, stairs, and water.

This solution is unique because it takes the form of a shoe, this is advantageous because the user does not need to hold a stick or another contraption with them and it can seamlessly be incorporated into their lives. However, there are a few demerits to such a system, including the fact that we do not know if such a system would work in all sorts of environments and weathers. Along with this, it might give false signals, since your shoes are on your feet the odds of a camera or SONAR system getting covered by debris is pretty high.

All in all, most of these systems have the same fundamental problems. Most of these systems fail to deploy any sort of object or image detection models which prevents them from predicting the types of the objects in their path. Along with this, there should be some sort of system to deliver information to the blind in a more efficient manner; auditory or even tactile cues can overwhelm the user with multiple outputs in a matter of seconds. Delivering a lot of information in a short time period can prove to be tricky, so future devices may utilize constant haptic feedback allowing users to better understand. Along with this, it is extremely important to make sure that whatever device is used, it is built in such a way that it can survive all kinds of weather and terrain.

I. PROJECT LOUIS: OUR SOLUTION TO A WALKING STICK FOR THE BLIND

Our solution, called Project Louis, will assist the visually impaired in navigating through novel areas in a non-obstructive manner. The basic working principle is that it helps the blind navigate urban areas by sending constant vibrations that increase as objects get closer.

Project Louis is constructed using a range of materials and components, including an industrial microcontroller ATMEGA8, a 3.7V 2000mAh Lithium-ion cell with a corresponding holder, and a USB-C charging module equipped with a Battery Management System (BMS). Power regulation is managed by a 5V boost converter, while a voltage sensor monitors the battery status. The device features a buzzer, three NPN transistors, resistors of 1Kohm and 10Kohm values, and capacitors (22pF and 100nF). It is assembled on a Zero PCB board and includes two vibration motors to provide haptic feedback and an ultrasonic sensor for object detection. User interaction is facilitated by a 4-position side switch and a large push-button switch, to toggle between the different modes. The wiring is secured with connectors, and the device is enclosed in a 3D-printed case, which also includes a cane holder and Braille labels. Additionally, custom PCB boards are used for the motherboard and switches.

Fig. 1. CAD Visualisation Of Project Louis (Back)

The cane holder is such that it allows users to seamlessly add Louis to any existing stick simply by screwing it in. It is imperative to put ease of use and comfort first for such devices, by adding this feature we allow the user to add Louis into their lives rather than causing them to change it. While this may seem like a small feature from the outside, after conducting interviews at the Amar Colony Institution for the Blind in New Delhi, we found that this feature is actually very helpful.

Louis features a battery status indicator accessible via a push button, allowing users to monitor various battery levels. It offers a 50-hour backup on a single full charge, with a complete charging cycle taking approximately 3 hours using any standard Android USB-C cable and charger. The battery status is communicated through a combination of beeps and vibrations. At a critical level (below 30%), the device emits continuous short beeps and vibrations while operating in any mode, and similarly when the push button is pressed, indicating the need for immediate charging. When the battery is between 30% and 40%, pressing the push button triggers four beeps accompanied by vibrations lasting 2.4 seconds, signaling a low battery status. A moderate battery level (40% to 60%) is indicated by three beeps with vibrations lasting 1.8 seconds when the button is pressed. For a high battery level (60% to 80%), the device emits two beeps with vibrations lasting 1.2 seconds upon pressing the button. Finally, a fully charged battery (80% to 100%) is signaled by a single continuous beep and vibration lasting 1 second. These indicators provide a clear, audible, and tactile method for users to assess the battery status, ensuring timely recharging and uninterrupted device functionality.

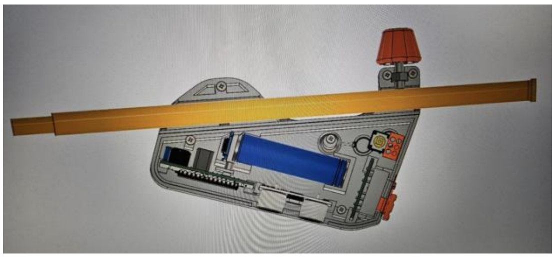

Fig. 2. CAD Visualisation Of Project Louis (Side)

Fig. 3 CAD Visualisation Of Project Louis (Front)

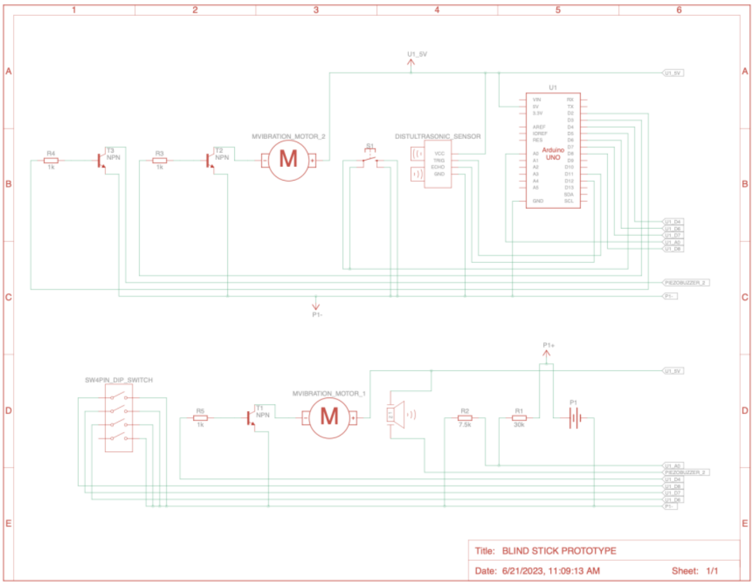

Fig. 4. Circuit Diagram Of System

Louis solves the tricky problem of providing output to users by providing active and constant haptic feedback rather than single audios or vibrations, which can often be confusing and overwhelming for the user. Louis provides a different degree of vibration as objects begin to move closer to the sensor, the distance of engagement varies with changes in modes.

For object detection, Project Louis has three modes (indoor, outdoor and open area) that vary the vibrations that the user experiences. The difference between the three modes is the distance at which it begins its haptic feedback and the distance at which the feedback intensifies. The indoor mode begins to provide feedback at 60 cm, at 30 cm the feedback begins to increase. The outdoor mode begins to provide feedback at 120 cm increasing feedback at 60 cm and the open area mode provides initial feedbacks from 300 cm intensifying at 120 cm. These three modes and the range for each mode has been made under the advice and feedback from interviews conducted.

The tactile and auditory cue issue which was extremely prevalent with previous devices is solved by Louis. It does this by continuing to vibrate as long as anything is in its path; as objects move closer the vibrations get more intense hence alerting users of the distance of the object. In this way, we have built a framework that is non-disruptive or compromising to the flow of daily life and daily interactions hence allowing our users to use this device out in public without implications.

Louis also has braille present in various places to allow the user to toggle between different modes via touch, as well as to find the charging ports, which we've seen to improve overall user experience. The system is a great starting point, serving as an important catalyst to the rise of assistive technology in India. With this simple system, users are able to improve their experiences in urban areas at a small cost and in a relatively simple manner.

Not dissimilar to previously discussed systems in Section II.C, there are specific demerits which need to be addressed in future iterations of the device. The first is the fact that with just one ultrasonic sensor vertically-placed, the actual field-of-view of the system (4° horizontal) is relatively narrow, hence failing to provide any information about directions other than nearly straight ahead. Along with this, the system fails to judge the type of different objects that it senses; this is one place where there is plenty of scope to improve. Unlike other solutions, Louis does not connect to or contain any GPS systems or additional safety features which could also be another point on which we can build up on with relative ease. In order to improve the system, future iterations of Louis aim to include a camera, with which we hope to add object detection that announces what type of object is directly ahead of the person. These two basic inputs (camera and ultrasonic sensor) and simple outputs (tactile and auditory cues) will help the blind navigate through novel urban environments extremely well without overwhelming the user and helping them stay in safe areas while well-aware of surrounding objects.

II. DISCUSSION AND CONCLUSION

Through this study we found that there is a large scope of development of assistive technology devices. We found that most good solutions still have avenues for improvement by simplifying the processes and functions of their technology. Essentially, developers must make sure to use simple interfaces and avoid 'over-engineering', or otherwise adding complex features that might serve to confuse or overwhelm the user. As shown in this paper, there has been plenty of work specifically in mapping surrounding environments, helping to feed, and navigation; a primary opportunity for improvement of these technologies remains making these technologies affordable, accessible, and non-obstructive. Once these technologies have time to be properly tested and put to commercial use, the government can help improve inclusion in their urban areas by providing funds to institutions so that they can purchase such technologies for those in need. There are a few ethical considerations and issues that need to be discussed with the implementation of such devices, such as the fact that cameras used for image and object detection will be recording in public areas, possibly taping people without their consent, subject to varied regulations across jurisdictions. Along with this, if a device fails to recognise potential threats in the immediate environment of the user and does not provide safe instruction, then liability and insurance for these incidents must be considered. All in all, the work being done in this field is inspiring, and by doing this research, we hope to make a small difference to the big obstacle of a lack of accessibility.

III. ACKNOWLEDGMENT

Thank you for the guidance of Anish Bhattacharya, mentor from the University of Pennsylvania in the development of this research paper.

REFERENCES

1. Shukla, Kriti, et al. "Access to assistive technology for people with visualiImpairment." *IHOPE Journal of Ophthalmology*, Scientific Scholar, 13 Jan. 2023, ihopejournalofophthalmology.com/access-to-assistive-technology-for-people-with-visual-impairment/#:~:text=The%20prevalence%20of%20the%20need,visual%20impairment%20(from%20APL).&text=In%20all%20surveyed%20countries%2C%20the,50%20types%20of%20assistive%20products.

2. Gallenberger, Daniel, et al. *Transfer depends on acquisition: analyzing manipulation ...*, personalrobotics.cs.washington.edu/publications/gallenberger2019skewering.pdf. Accessed 21 Aug. 2024.
3. Herlant, Laura. "Algorithms, implementation, and studies on eating with a shared control robot arm." *Carnegie Mellon University*, 2018, doi.org/10.1184/R1/6714647.
4. Schr¨oer, Sebastian, et al. "Autonomous multi-sensory robotic assistant for a drinking task | Request PDF." *Research Gate*, 2015, www.researchgate.net/publication/334769278_Autonomous_Multi-Sensory_Robotic_Assistant_for_a_Drinking_Task.
5. Kadhim, Mais R., and Bushra K. Oleiwi. "Blind assistive system based on real time object recognition using machine learning." *IASJ*, 2022, www.iasj.net/iasj/download/7aa0e882f11e92a8.
6. Qazi, Tasmiyah. "Third eye: assistive technology for the visually Impaired." *Escholarship*, 2019, escholarship.org/content/qt0s2482s4/qt0s2482s4_noSplash_4b027f106366ca3ccb85352e2c37ed1d.pdf?t=pwht11.
7. Redmon, Joseph, et al. "You Only Look Once: unified, real-time object detection." *arXiv.Org*, 9 May 2016, arxiv.org/abs/1506.02640.
8. "Smart walking stick For visually impaired." *Cloudfront*, dhg1h5j42swfq.cloudfront.net/2021/10/27174530/1yws3spnupn5q9i7ymesoagu52rdkcmqmp0juk49oajk9cbm4xgsapkgnrv6mxi3pcqmt1saj5wsn3ek1461-1.pdf. Accessed 21 Aug. 2024.
9. Nathan, Shelena S, et al. "Design of smart walking shoe for visually impaired people." *Journal of Advanced Research in Applied Mechanics*, 2023.
10. D, Sathya. "Smart walking stick for blind person." *International Journal of Pure and Applied Mathematics*, 2018, acadpubl.eu/hub/2018-118-21/articles/21f/1.pdf.