An Affordable and Attachable Electronic Device for the Blind

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***Abstract*— This paper introduces the development and evaluation of an affordable device which complements the workings of a white cane. The attachable device is bolstered with environmental sensing sonars, allowing the visually impaired to navigate around safely and efficiently. With the usage of ultrasonic sensors, hanging objects, incoming step-down and walls can be detected. Users are cautioned of potential risks through audio and vibration cues. A 3D printed casing was designed to house the components, allowing costs to be kept low and prototypes to be developed rapidly. Initial tests on blindfolded test subjects in both indoor and outdoor conditions have proved to be successful.**

I. Introduction

The white cane serves as a mobilty tool for the visually handicapped. It has been so successful in its mission that it is now immediately associated with the visually handicapped. The white cane is able to detect objects, holes and steps on the ground and this physical contact with the ground informs the user on the conditions of the path ahead. The white cane also provides an added assurance to the visually handicapped and forewarns other pedestrians, allowing the white cane user to have the right of way. However, there are several limitations to the white cane. One major disadvantage would be the inability to detect hanging or protruding objects above the waist level. This inability has resulted in many head injuries sustained by the visually impaired users [1]. The second disadvantage is the white cane's inability to alert the user on its location. With 82% of the visually impaired being aged 50 and above [2], many tend to misplace their white canes.

According to the World Health Organisation (WHO), 285 million people are estimated to be visually impaired, of which 90% live in low-income settings[2]. As such, there is a need to develop a device which is both functionally reliable and affordable.

A. Mobility Aids

Over the years, companies and researchers have introduced several types of mobility aids which can be used to detect hanging objects and steps.

B. Guide Dogs

Guide dogs serves as a trusted companion and a navigator to the visually impaired. These highly trained dogs are able to detect obstacles in the visually impaired's path and navigate them around it. However, guide dogs are expensive to train and care for [3] and they have a short working lifespan of five to 8 years [4]. Training period for the visually impaired user can stretch from three to 12 months [4]. Furthermore, many societies and communities have yet to be accustomed to having dogs in public spaces.

C. Electronic Travel Aids (ETAs)

Several ETAs which are integrated with the white cane have been developed. The UltraCane is a white cane which incorporates ultrasonic sensors in it to detect hanging objects and obstacles 2 to 4 m ahead of user [5]. Feedback on potential risks are provided through vibrations signals.

While the UltraCane is a cane by itself, others such as the Haptic Alerts for Low-hanging Obstacles (HALO) system comes as an attachment to the white cane [6]. Similar to the the UltraCane, the HALO system relies on ultrasonic and vibration motors in detecting and alerting users on the presence of hanging objects.

The GuideCane which offers a cheaper alternative to guide dogs seeks to detect obstacles, maps out an alternative route for the visually impaired user to take and finally navigate the user through the proposed route. Using an array of 10 ultrasonic sensors, the GuideCane creates a 2 Dimensional (2D) map of the user's surroundings. Based on the information obtained from the 2D map, an unobstructed route will be proposed instantaneously [7].

[8] introduces the usage of a Light Detection and Ranging sensor (LIDAR), a tri-axial accelerometer and a tactile belt in providing mobility assistance to the visually impaired. Without the usage of the white cane, the LIDAR sensor's primary function is to collect proximity data on the path ahead. While walking and employing the sweeping motion, obstacles and steps ahead can be detected. This is made possible as the device presets a range of threshold values. If the distance from the LIDAR sensor to the floor increases drastically, it will indicate a step ahead. The accelerometer allows the user to switch between the floor and frontal mode automatically.

The major disadvantages of the above solutions are cost, weight, inability to alert user on the white cane's location and the inability to detect steps or side walls, which provides the blind support when navigating a flight of steps. Frontal scanning may prove to be redundant with the use of a white cane since objects such as tables and chairs can be easily detected using the latter. Heavy devices will make travelling on uneven grounds or stairs difficult. Moreover, devices which are integrated into the canes will render the visually impaired's existing cane useless, resulting in wastage.

D. Mobile Applications

With smartphones equipped with voice recognition and voice assisted capabilities, an increasing number of visually impaired are using smartphones.

The Blind Sight mobile application utilises the proximity and gesture sensors on a smartphone to detect objects five cm away. When objects are detected, audio cues and vibration signals are sent to the user.

Blind Assistant uses sound waves to create echoes. This form of echolocation technology is based on sampling rate, volume and signal to noise ratio. By calculating the time taken for the echoes to return, distance from the phone to the object can be established. Alerts will be sent to the user when objects are detected 40 to 70 cm away.

The vOICe for Android translates live camera feeds into soundscapes. Using pitch to represent the height of an object and volume to represent the brightness of the object present in the camera feed, the sounds produced creates a virtual reality sound image for a trained user.

While mobile applications are a convenient choice of proximity detection tool. Mastery of the technology involved in each application may take a long period of time. The lack of voice commands may also prove to be a challenge. While these applications can function independently of the white cane, they lack the physical assurance and cues on the type of ground which the conventional cane provides. They do not provide the critical capabilities which the cane offers, such as the ability to forewarn and giving the user sufficient buffer time to react to obstacles or steps ahead. Moreover, the directed area of interest is either unable to detect hanging objects or it is not focused on doing so.

II. Functional Specifications

After several conversations and receiving formal white cane training from the Singapore Association of the Visually Handicapped's (SAVH) Occupational Therapist, we focused on developing an affordable, attachable, functionally reliable device which would complement the workings of the traditional white cane.

The device should utilise proximity detection sensors to detect protruding and hanging objects. A small and light micro-controller will process these proximity data and output vibration and audio signals accordingly. The device should also be able to detect and inform users on the nature of the drops on ground level ahead (step or cliff). The ability to detect side walls or handrails will allow the visually impaired to move towards them and use them in navigating a flight of stairs.

Alerts to the visually impaired user should come in the form of vibration and audio signals. As audio signals can be masked by environmental noise, these audio signals should be transmitted to the user via a earpiece. These earphones should not be noise cancelling as environmental sounds can be vital for the visually impaired's safety while moving around.

As the length of the white canes is proportionate to the visually impaired user's height, white canes come in differing lengths. The device should be portable across all lengths of canes, hence a button should be implemented to set the different threshold lengths. Exceeding that threshold length by a few centimetres would represent a step, exceeding it by a metre would represent a steep drop on the ground level.

The device should be able to communicate with a mobile application. When activated by the mobile application, a buzzer should sound off, allowing the visually impaired to locate his or her white cane with the help of the audio cues. As our users are visually impaired, the mobile application should have a simple interface, voice commands and instructions given should be clear and straightforward.

III. System Design

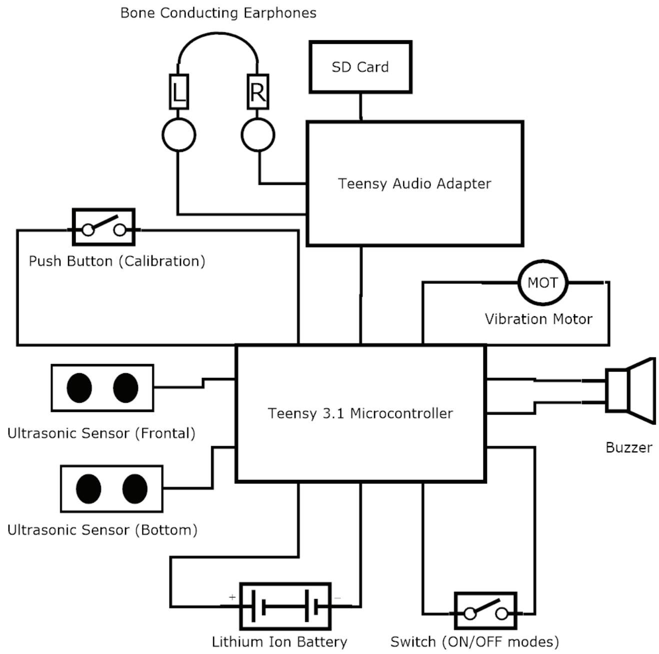

Figure 1: Block Diagram

A. Electronic Components

As depicted in Figure 1, the device utilises two ultrasonic sensors to detect hanging objects and steps with a frontal and downward range of between 0.02 m to 3.00 m. A Teensy 3.1, Cortex-M4 core micro-controller processes all incoming sensory data into audio and vibration output signals. Voice commands are transmitted to the user via a Bone Conducting Headphone connected to a Teensy Audio Adapter. A buzzer and a vibration motor translate proximity information into alerts where faster tones or vibrations indicate closer proximity.

A switch is implemented to switch the device on and off. When switched "on", the device will be able to detect hanging objects and steps. When switched "off", the Bluetooth module will be activated and awaits the user to connect via a Mobile App to activate the buzzer. A push button is used to set the threshold range, allowing the device to be implemented on all types of white canes. A rechargeable lithium-ion battery is used to power the device.

B. *Choice of Components*

The Arduino Uno runs on ATmega328 whereas Teensy 3.1 runs on Cortex-M4. Both boards are capable of processing incoming data into vibration and audio signals. The Teensy 3.1 micro-controller was finally selected over the Arduino Uno because of its light weight, smaller size and lower cost.

In the early stages of the project, experiments were carried out to determine if ultrasonic or infrared sensors were more reliable in detecting proximity in indoor, outdoor, day and night conditions. The PING ultrasonic sensor was found to have outperformed SHARP's 2Y0A02 infrared sensor.

IV. IMPLEMENTATION

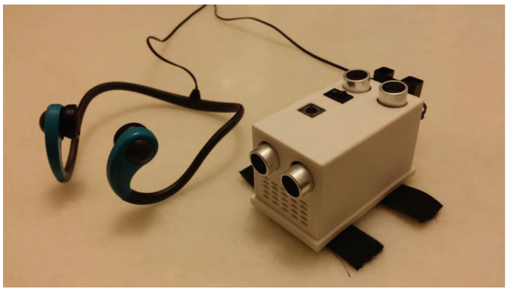

Figure 2: Device with Bone Conducting Earphones

A. *Functionalities*

Before turning the device on, the visually impaired user should be wearing the Bone Conducting Earphones. In a conventional earphone, sound waves travel to the eardrum and vibrate the eardrum. The eardrum processes these vibrations and in turn vibrates the cochlea. The cochlea translates these vibrations into electrical signals which are sent to the brain and interpretated as sound. The Bone Conducting Earphones skips the front few steps and vibrates the cochlea directly. This leaves the ears open and users are able to listen to both environmental and device produced sounds.

After turning the switch on, the device sets the threshold value needed for steps and drop-offs detection. This calibration is done through the push of a button and it should be done when the white cane is positioned vertically upright. User can re-calibrate the threshold value anytime. During calibration, only the bottom facing ultrasonic sensor is activated. After obtaining the average distance between the sensor and the floor, 30 cm is added to the average distance to obtain the threshold value. This 30 cm will provide a buffer as extra height is created when the user is employing the tapping technique instead of the usual sweeping technique.

When the user navigates around, the top facing ultrasonic sensors triggers an ultrasonic wave (40kHz tone) every 2 µs, whenever an obstacle comes within a range of 1.20 m, the vibration and audio signals are sent to the user. This will caution the user of an approaching hanging or protruding object.

As the user taps or sweeps his cane, when a drop-off or step is detected, the user will usually position his cane vertically, allowing the user to feel for the step below. Side walls or railings and the nature of the drop-off will be detected and the user will be alerted.

Upon reaching a familiar location, users may switch off the device and move about without the use of the white cane. The Bluetooth module is turned on and awaits pairing from a mobile application. After pairing, a visually impaired user will be able to trigger a buzzer within the device, allowing the user to locate his or her white cane more efficiently in the event the user misplace his or her white cane.

B. *Prototype Design*

Designed using Autodesk's 123D Design, the casing went through several rounds of design iterations. In each iteration, the design was 3D printed, tested, reviewed and subsequently refined. Our focus were on designing a casing which housed the sensors in the best position for them to perform optimally, a device which works for both left and right handers and also one which would provide an unobstructed access to the button and switch.

V. EVALUATION

Figure 3: Wong Hejun demonstrates the device

Development of the device was done incrementally. Individual functions were tested before merging with the other functions. System tests were conducted after each merger of function to identify errors and rectify them. After the development phase, we conducted three types of experiments to evaluate the performance of the device.

A. *Detection of Hanging and Protruding Objects*

8 blindfolded test subjects, aged between 22 to 64 years were asked to navigate through a playground for 10 minutes. They were told not to stop walking during the test. The playground being catered to kids as young as two years of age had structures, slide, pull-up bars and a speaking tube which were between the test subjects' waist to head level.

Results from the test demonstrated that the device was able to detect hanging and protruding objects with 100% success rate. Each time the audio and vibration signals alerted the user of a potential risk, they stopped moving and felt their way through the obstacle with a stretched out hand.

B. *Detection of Side Walls and Steps*

The same 8 test subjects who participated in Experiment A, participated in Experiment B. For this experiment, a briefing followed by a demonstration on how a visually impaired would usually navigate a flight of steps was made. (After detecting a step up or down, the visually impaired will usually hold the white cane vertically, allowing them to feel the step ahead.) The test subjects were asked to navigate a short distance towards the flight of steps and down that flight of steps.

Results showed that the test subjects were moving cautiously after being told to navigate a flight of steps. They were able to make use of the frontal ultrasonic sensor in detecting a nearby railing. All participants held on to the railing while navigating down the steps. The physical contact of the step coupled with the vice commands issued, gave participants greater confidence and they moved faster.

C. Locating of Device using Audio cues

Six blindfolded test subjects, aged between three to 64 years were asked to point in the direction where they thought the device was located, after the buzzer of the device was triggered by the Mobile Application. The device was shifted and triggered 10 times at 8 different positions.

The main result of the test is that all the adult participants could accurately pinpoint the direction of the device with 90% to 100 % accuracy. The three year old test subject could also pinpoint the direction where the device was located with 100% accuracy, however this was achieved after a reminder on the task. This could be attributed to several factors such as the lack of understanding of the task.

EXPERIMENTS	TEST SUBJECTS (NUMBER)	AGE RANGE	SUCCESS RATE (%)
Detection of Hanging and Protruding Objects	8	22 – 64	100
Detection of Side Walls and Steps	8	22 – 64	100
Locating of Device using Audio cues	6	3 - 64	90

VI. Future Work

The tests were conducted with human subjects who were visually abled and blindfolded. Tests performed on visually impaired users may yield a differing set of results and feedback.

Further testing can be done on objects with different shapes and sizes to test the limitations of the ultrasonic sensors.

Wireless charging capability can be introduced in the next version. As the device is currently charged via a USB port, visually impaired users may spend a considerable amount of time trying to locate and align the USB port and cable.

As the Mobile Application developed is only for the Android platform, future applications can be coded using PhoneGap. This will allow the application to be deployed onto all major phone operating systems.

VII. Conclusion

The device was developed in the interests of the Blind Community. Identifying and referencing current technologies seek to better subsequent works. The device introduced in this paper differs itself from current works in the following ways:

1. Physical Object
   a. The added assurance and support which come with the cane is hard to replicate on contactless devices.
2. Attachable
   a. Users can continue using their existing canes which they are accustomed to.
   b. Manufacturing costs are minimized since no cost is required to manufacture the cane.
3. Detection of Steps
   a. A key difference lies in the cost of technology that is used to detect steps. Laser sensors may produce highly accurate results but the balance between cost and functionality should always be weighed. Ultrasonic sensors could deliver similar results at a much lower cost.
4. 3D Designed and Printed
   a. Can be reproduced quickly at a low cost.
5. Mobile Application
   a. Saves time and energy in cane location
   b. Great potential for future development
6. Low Cost
   a. Total cost for producing the device is USD127.50
   b. A pair of Bone Conducting Headphones can increase the cost by an additional USD50

In conclusion, the authors hope that future development will raise the quality of life of the Blind Community.

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