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SMART BLIND KIT: ARDUINO-BASED WEARABLE ASSISTIVE DEVICE FOR REAL-TIME OBSTACLE DETECTION AND MOBILITY SUPPORT

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Abstract
The demand of affordable and efficient assistive technology has increased with the increasing number of the sight impaired people across the world. The current research introduces the design and construction of Smart Blind Kit, a low-cost sensor-based portable navigation aid designed in open-source hardware and a combination of low-cost parts. The system uses Arduino Uno microcontroller together with ultrasonic and infrared sensors, piezo buzzer, and RF-based locator module in order to offer real-time obstacle detection using vibration module and audio-based feedback. The modular architecture comprises sensor-on-sandal to sense the ground level obstacles and an IR-sensor band on the head to identify the hazards in the lateral and upper sides. A complete design of a hardware prototype was developed and field-tested. Experiments showed consistent performance in detecting the obstacles with a very low latency and a comfortable and easy-to-learn style of feedback. With the number of six ultrasonic sensors constructed on the shape of a headband, the ultrasonic circuit can scan a large area of field of view, whereas the sandal circuit linking numerous IR sensors and one ultrasonic sensor can offer an extended scope of space. The breadboards were used to build both circuit schematics and to validate it, which is included in the contribution. The usability, accuracy, and the power consumption of the system were checked. It was found to be useful in indoor and semi-outdoors areas where test users gave positive reviews to its use. The fact that the device consumes low power, has an ergonomics of wearable and is scalable supplements the fact that the device will be ideal to be deployed in developing countries. This project provides a scalable backdrop to the future additions of GPS navigation, smartphone interconnectivity, and voice control and is a potentially value-adding solution to facilitate safe and independent movement in visually impaired persons.

INTRODUCTION

One of the most important abilities of a person is the sense of vision, as it allows the individual to see, communicated and orient himself within the surrounding environment. The World Health Organization (WHO) reports that over 285 million individuals have visual impairment around the globe with around about 39 million totally blind and 246 million vision impaired [1]. Ninety percent of these people reside in third world countries where economic conditions do not allow many to get access to necessary assistive technologies [1]. The individuals in such areas with visual impairments find it very difficult doing their day-to-day activities, orientating in new places, and securing their personal lives especially when they are not in constant touch with others. Historically, the white cane and guide dogs are some of the aids that have been used to help the blind move around. These solutions are effective although to some extent they have limitations. The white cane has a strictly mechanical application and can only locate ground level obstacles within and around the user hence this limits its use to a certain area [2]. Guide dogs on the other hand, take time to train, are expensive to maintain in terms of maintenance and also, they last only a short period of time [3]. Such limitations highlight the necessity of technological solutions that should be affordable, applicable, and usable by many people, being friendly with various needs of the visually impaired. The current efficient developments of embedded systems, sensor technologies, and microcontrollers have enabled the creations of smart assistive devices to provide better abilities than traditional instruments do. As one such sensor, ultrasonic sensing technology has become a viable candidate in many regards because of its durability, low cost, and its ability to detect objects irrespective of the ambient lighting [4]. Complimented with infrared (IR) sensors, a microcontroller like Arduino Uno, a portable system that can assist the navigation process by detection in real-time and generation of alerts about obstacles should be possible [5].

This paper gives the design and implementation of Smart Ultrasonic-Based Assistive Device in helping the researcher to support the visually impaired. The system contains a headband and a mini-stick in a form of handheld device both of which are embedded with ultrasonic and IR sensors. The sensors identify the objects in the immediate location and transmit the signals to a microcontroller that interprets the data and transmits signals to a buzzer that will act as an audio indicator to the operator. Also, there is the remote-controlled locator feature that aids users to keep track of their assistive device in cases where they lose it [6]. The suggested system can be described as associated with a low power consumption, affordability, lightweight form factor and more simplistic, thus, being the perfect candidate to be implemented in an environment with economic constraints. The project can exploit common, accessible parts, and easy assembly to close the divide between limited technologies available to the blind. The rest of the paper will be divided as follows: section 2 involves a review of literature and technology currently deployed in aids to the visually impaired. In section 3 the architecture and method are described. The process of the implementation and testing of the device is described in the section 4. The results and the possible improvements are discussed in section 5. The paper ends with section 6 that describes future work.

Literature Review

The production of assistive technologies to help visually impaired has come up with a very unprecedented and tremendous growth over the past few years especially with the incorporation of microcontrollers, sensor technologies and wearable computers. Traditional devices like the white cane are only capable of providing a user with limited spatial information, mainly at ground level and within the physical reach of the cane user [1]. Though guide dogs can provide higher mobility and obstacle identification, their expensive nature, short life and the need to conduct comprehensive training make guides inaccessible to the majority of population, particularly, in low-income nations [2]. In order to overcome these shortcomings, studies have looked into the use of electronic travel aids (ETAs), which augment navigation by identifying obstacles through the sensors and technologies like ultrasonic, infrared (IR), and camera-based ones [3]. An initial solution to this was the infrared emitter detecting objects and notifying the user through vibration or sound [4]. Nevertheless, IR sensors have environmental interferences, lack of long range and accuracy especially in outdoor conditions [5].

The reliability and low cost of Ultrasonic sensors that use the principle of echo-location have made them popular. They are capable of measuring the distance separating the user and an obstacle by detecting high-frequency sound waves and computing the time required by the echo to reach him back. Kuchenbecker and Wang suggested a system referred to as HALO which applies haptic alerts that prompts the user to be informed about the presence of low-hanging obstacles using ultrasonic feedback [6]. Likewise, having performed the same kind of work with an augmented white cane added with multimodal haptic feedback and ultrasonic sensing, Gallo et al. developed the project allowing to improve the real-time perception of the surroundings [7].

A number of research endeavors have created smart walking sticks with ultrasonic and global positioning system (GPS) modules to navigate inside and outside buildings. Portable navigation aid proposed by Tamjidi et al. estimates the 6-DOF pose of the user based on sensor data and shows navigational guidance hints on the smartphone app [8]. Pereira et al. worked out a guide system that exploits the body area based network by employing the ultrasonic sensors to form a spatial representation that outlines the space in which the user is located [9]. Additional methods make use of artificial intelligence, and machine vision. Joao Jose et al. acquired local navigational guide that has stereo vision to help the visually impaired identify things and calculate distances [10]. Despite the richness in the information it provides, vision-based systems are computationally intensive, power-consuming, and usually costly which makes such systems inapplicable in less developed countries.

Although these innovations have occurred, most of the currently available systems are either expensive, complex, or fail to be vaunt robust amid changes in the environmental parameters. This gap has

Influenced the creation of simple wearable systems that utilize sensors in bringing simplified navigational assistance as required but being low-priced, lightweight, and easiness to operate. The combination of ultrasonic and IR sensors with Arduino in our proposed system is in line with such priorities, being based on the requirements of the core functionality and economical. Moreover, smartphone connection can be done using some devices like 1Sheeld interface, which expands responsiveness by adding vocal based applications. As shown by Aono et al., the use of voice-based feedback is very effective in relation to reaction time and satisfaction among the blind users [11].

Table 1: Comparative Analysis of Related Works on Assistive Devices for the Visually Impaired

S. No	Study / System	Technology Used	Merits	Demerits / Limitations
1	HALO by Kuchenbecker & Wang [6]	Ultrasonic sensing with haptic feedback	Detects low-hanging obstacles; non-intrusive haptic alerts	Focused only on vertical obstacles; lacks modular design for full navigation
2	Augmented White Cane by Gallo et al. [7]	Ultrasonic sensors + vibration feedback	Multimodal alerts; improved user awareness	Not wearable; dependent on traditional cane form; limited object classification
3	Smart Cane by Tamjidi et al. [8]	Ultrasonic + 6-DOF pose estimation + smartphone app	GPS-integrated mobility; accurate pose estimation	High cost; complex design; not ideal for rural or low-resource settings
4	Stereo Vision Aid by João José et al. [10]	Stereo camera-based navigation	Real-time object recognition and local navigation	High computational requirements; performance degrades in poor lighting
5	Blind Guide by Pereira et al. [9]	Ultrasonic sensor-based body area network	Effective spatial mapping of surroundings	Requires multiple sensors and wearables; not easily scalable
6	Voice-Controlled Stick by Aono et al. [11]	Voice command + obstacle detection	Voice-assisted control; user-friendly for tech-savvy individuals	Not suitable in noisy environments; language-dependent limitations
7	IR-based detection by Khlaikhayai et al. [4]	IR sensors + audio warning system	Basic obstacle detection; cost-effective	Affected by ambient light; short detection range (4–30 cm)
8	**Our Proposed Work: Smart Blind Kit**	**Ultrasonic + IR sensors, Arduino, RF Locator, Buzzer Interface**	**Wearable, affordable, multi-sensor, modular, indoor/outdoor use, audio feedback, remote locator**	**Limited object classification; can be enhanced with GPS, voice commands, and smartphone integration in future work**

The comparison in Table 1 shows that assistive technologies developed to help the blind passed through a whole line of the simplest IR-detection devices to the more comprehensive vision and GPS-equipped systems. Although each of these solutions has certain benefits e.g., better haptic feedback, exact localization or voice assistance, common with all solutions is huge costs, complexity, detection range, or the ability to adapt to real life in low-resource conditions. As an example, vision-based aids offer object recognition in great detail yet this technique has power intensity and light sensitivity issues. On the contrary, IR and ultrasonic type tools are less expensive but are not comprehensive and flexible. The limitations associated with the employment of the aforementioned solutions are overcome in our suggested smart blind kit that includes an assembly of sensors (ultrasonic with IR), microcontroller (Arduino), and basic usability functionality (audio feedback and an RF-based remote locator) into a wearable device, cost-competitive, and modular system. The design addresses a significant research gap since it balances on functionality, simplicity, and affordability particularly to the users back in the developing countries. The depicted literature highlights the necessity of low complexity and effective navigational aid that will enable visually impaired users to move freely and safely. Our device continues this work by providing a prototype, wearable smart blind tray, which is aimed to be real world usable, particularly in low resources settings.

System Design and Methodology

The smart blind kit i.e. the proposed device is aimed to be a type of wearable assistive gadget that would allow a visually impaired user to identify and even react to obstacles in the immediate surroundings. The system combines several units like ultrasonic sensors, Infrared (IR) sensors, microcontroller (Arduino Uno) and feedbacks using vibration module, a buzzer and RF-based locator. The main goal of this design will be a combination of accurate real-time obstacle detection and ease of use using clear audio signals (instead of a screen) without paying a premium price or adding complexity, particularly to those that use the device in low-resource environments.

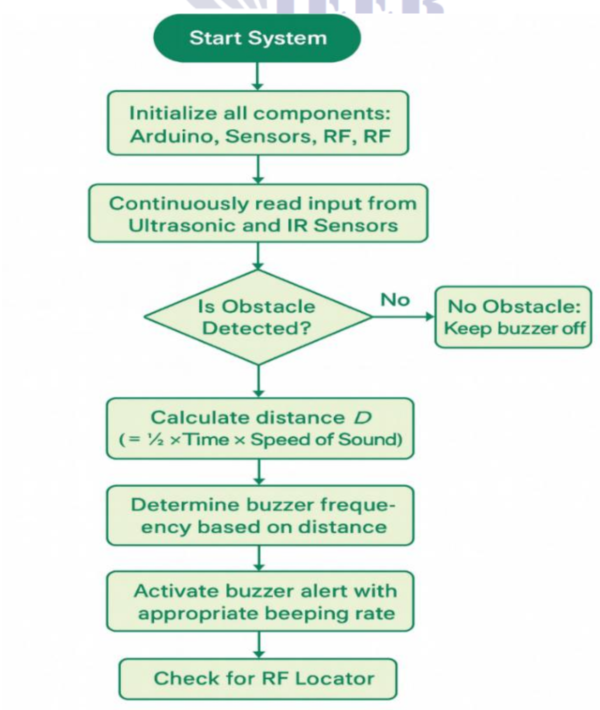

Figure 1: Flowchart of Methodology

The heart of the system is the Arduino Uno, which serves as the central processor component supported by the Arduino microcontroller that is in charge of provision of analog input and real time decision making. The sensor (HC-SR04) is mounted on the front of a lightweight handheld mini stick that will be used in detecting frontal and ground level obstacles by sending a ultrasonic wave and recording the time- of-flight of the echo. The IR sensors are located on both sides of a band on the head and the mini stick to detect obstacles on lateral sides over the range of 10-150 cm. After an obstacle has been detected by the sensors, the information is transmitted to the controller where it is interpreted and causes a buzzer to go off putting the user on alert. The frequency of the beeps given by the buzzer is inversely proportional to the distance between the obstacle and the robot: a continuous tone would warn the robot about an imminent danger (within 30 cm), whereas pulsed beeps of increasing frequency would warn of the obstacle being between 30 and 100 cm. This auditory feedback system enables the user to hear the hazards in the surroundings without seeing them or not using the touch. Also, the system has a remote locator capability using RF. In case the user loses the device, then he can press the button on the RF transmitter which will switch on the buzzer in the stick thereby assisting the user to detect that it is through sound.

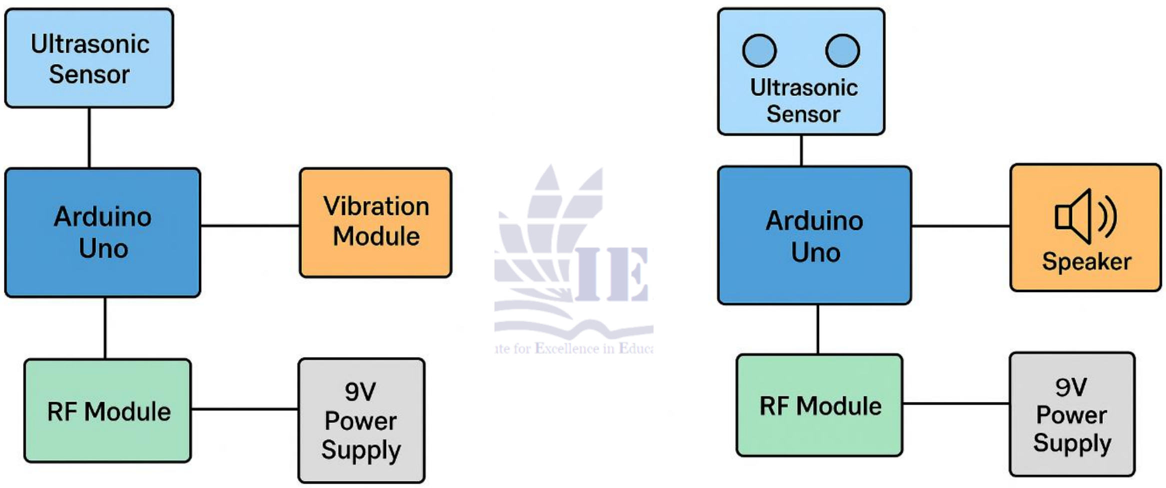

Figure 2: Block Diagram of The Proposed system

Figure 2 shows the block representation of the smart blind navigation system proposed as composed of two major wearable components the smart sandals unit and smart headband unit. These sandals have an ultrasonic sensor linked to a microcontroller Arduino Uno, which analyses obstacle distance information and activates a vibration module that notifies the wearer by the sense of touch. A 9V battery is used as a source of power and an RF module allows one to remotely activate or track the device. The headband implementation, in its turn, combines several ultrasonic sensors that allow to detect obstacles in the front and on the upper side. it employs a second Arduino Uno to crunch the data and activates a speaker to give real-time audio alert. There is also an RF module in this module and a designated 9V power supply. The modular and dual-channel design guarantees complete spatial awareness, where the visually impaired user is able to appreciate potential hazards both at foot- and head-level to improve personal safety and mobility.

Hardware Implementation

The hardware aspect of the suggested smart blind kit is aimed at creating a user-friendly assistive solution to visually impaired persons, compact, wearable, and with the maximum amount of connected electronic components. The design is built around the heart of the circuit board known as Arduino Uno, which is a competent and cost effective open-source microcontroller platform to handle all the inputs of the sensors and output functions. All the electronics are joined on a perforated board (perf board) making them common to be prototyped and altered. The front side of the handheld stick is made to host the ultrasonic sensor (HC-SR04), which will be the main sensor to locate an obstacle with frontal location. It produces sound waves of high frequencies and determines time consumed by the reflected wave to get back. Using the normal ultrasonic formulae equation, Arduino calculates the objects distance based on the echo time. The sensor can be used in both indoor and outdoor operations since it provides consistent results in the glass equivalent distances measurement of between 2 cm to 400 cm. The system is fitted with 4 IR sensors in order to improve environmental awareness. The forward-ground detection sensor is mounted on the stick, and the rest of them are attached horizontally to a lightweight headband in order to observe the obstacles that come to left and right sides simultaneously. The IR sensors utilize infrared light and the magnitude of reflected light by the objects in close proximity to the sensor hence they are the most effective option in detecting obstacles within short ranges of up to 150 cm.

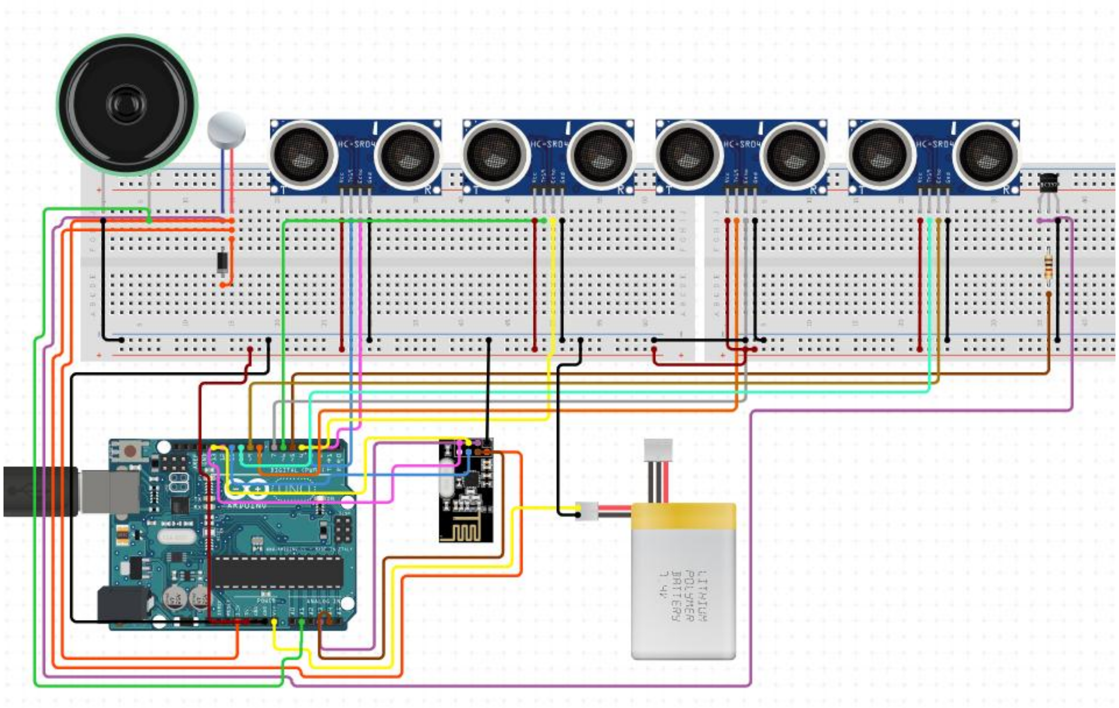

Figure 3. Circuit schematic of the headband module

The headband module was designed with a schematic of details of the circuit, as indicated in Figure 3. The system is based on the use of an Arduino Uno as the controller and can be connected to six ultrasonic sensors (HC-SR04) positioned horizontally one after another on the headband. Such arrangement makes the frontal and side obstacle much more visible in a large detection field, which can improve awareness of the space and the accuracy of the reaction. Each of the ultrasonic sensors is connected to the Arduino via its Trig and Echo connections; both are connected by jumper wires on a breadboard used in prototyping. Other components that are in the circuit include piezo buzzer which is an audio indicator depending on the closeness of the obstacle and a push button which is applicable in system operating reset or changing modes. It uses rechargeable Li-Po battery as the power supply which is regulated with enough voltage flowing on a regulated track. Moreover, a RF module has been added to the headband, which enables the wireless connectivity to be used in the future to connect to the smartphone application or cloud-based data logging. Modular wiring and breadboards allow quick experimentation, conformity and up-scaling the circuit to the wearable.

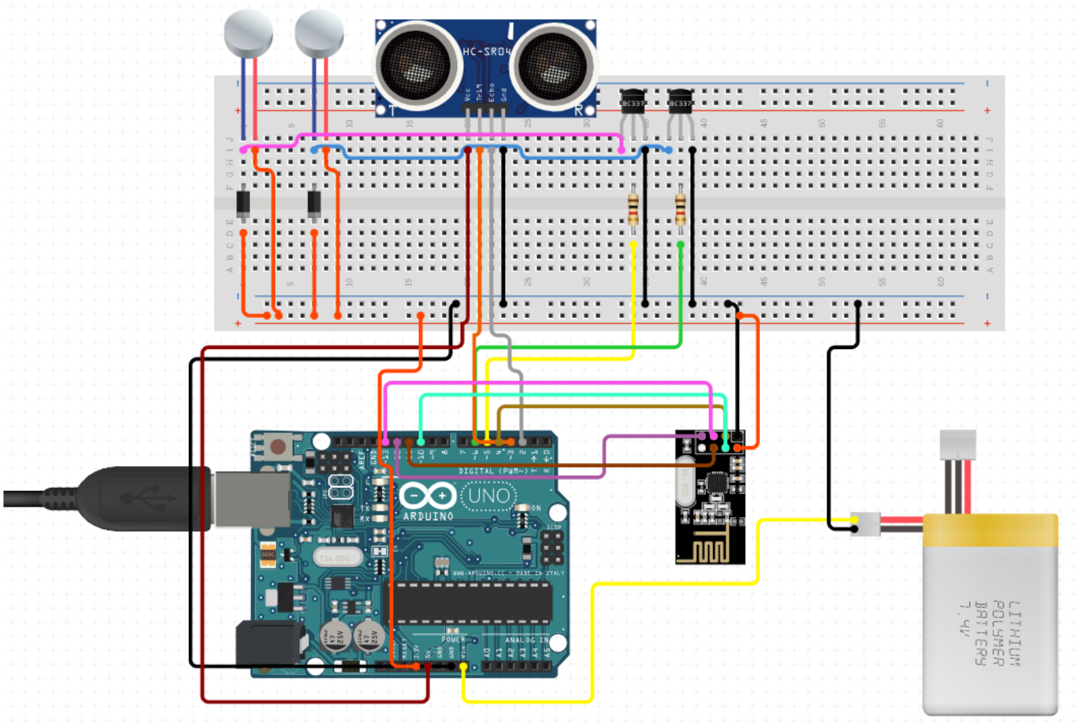

Figure 4. Circuit diagram of the smart sandals module

The smart sandals module gives an added extension to the headband system with emphasis on ground-level obstacle detection. The circuit diagram, depicted in Figure 4, displays how the sandals will integrate, an ultrasonic distance sensor (HC-SR04) to enable the frontal-looking ability and two IR-proximity sensors to measure the close objects or drop-offs at the vicinity of the feet. These sensors are fitted in the front of every sandal to give front and lateral awareness. This subsystem connects a sensor array to an Arduino Uno that is the primary controller of this subsystem. The sensor outputs are interpreted in real-time and the obstacle information is processed in order to initiate reaction outputs. A piezo buzzer is switched on to represent alert sounds to the user of the obstacles sensed within a pre-determined range distance. The buzzer gives various pattern of tone according to the closeness of the detected object. A Li-Po rechargeable battery supplies the system, and a regulator supplies 5V to all system parts. Also we have added a RF module, which can be used in the future to connect to mobile API, or to integrate with a centralized control logic. All these are connected with a breadboard and jumper wires permitting simple changes as far as testing and prototyping are involved.

A major output module is in the form of the buzzer, which interprets the proximity of the obstacles into a comprehensible sound. The Arduino controls the frequency of beeping of the buzzer real-time: a high frequency beep signal shows an obstacle is nearby, whereas low-frequency or no beep shows the path is clear. The situation awareness gain by using this frequency modulation does not need visual or tactile interactions by the user. In an exclusive nature, the system follows the approach of a Radio Frequency

(RF) receiver module. This enables the user to find the blind kit with the help of a small RF transmitter remote. Once triggered up, this remote signal to the RF module attached to the Arduino module and in turn, it leads to a signal to the buzzer button and assists the user in locating the lost stick without much difficulty. The hardware receives standard 9V battery and through a 7805 voltage regulator, this is converted to a steady 5V system that is Arduino compatible and compatible with the rest of the peripherals installed. Attention is paid to the minimum use of power so that the operational time could be long and it would be safe to use. These components would be securely fastened in a modular position so that easy repair or replenishing can be done. The hand held stick would be made with light materials to make it portable and the wiring would be covering with protective casing to avoid damages as well as the user. All in all, the hardware assembly will ensure that the system is light, ergonomic, and reliable and can adapt to various environments to make it a viable assistive guide in the daily use by visually impaired people.

Results and Discussion

The smart blind kit was effectively designed and put together with cheap and open source hardware. Once the hardware was integrated and the Arduino program successfully uploaded to the device, it underwent test functionality under various conditions of environment to test accuracy, responsiveness and ease of use. The settings of the tests were both indoors (e.g., home corridors, classroom) and outdoors (e.g., sidewalks and the open ground). A physical pre-prototype of the smart blind kit was able to be built and tested. The example of the device, as it is presented in Figure 5, is two sandals that have been modified to include ultrasonic sensors at frontal toe facet to sense near ground objects, stairs, or abrupt fall. The sensors are plugged together by insulated wires to a centrally placed central control that is within a transparent plastic casing with Arduino Uno board, voltage regulator circuit, and RF circuit. Alongside the foot-mounted sensors, a fabric headband provides infrared (IR) sensors located at different angles (left, front, and right) to help identify lateral and frontal detection of obstacles at an adult upper-body height. A small size of powers supply module of 9V battery is externalized and attached to the system through a safe power bus. The jumper connectors are used to design the wiring so that maintenance is easy, and pluggable so that they are modular and upgradable in future.

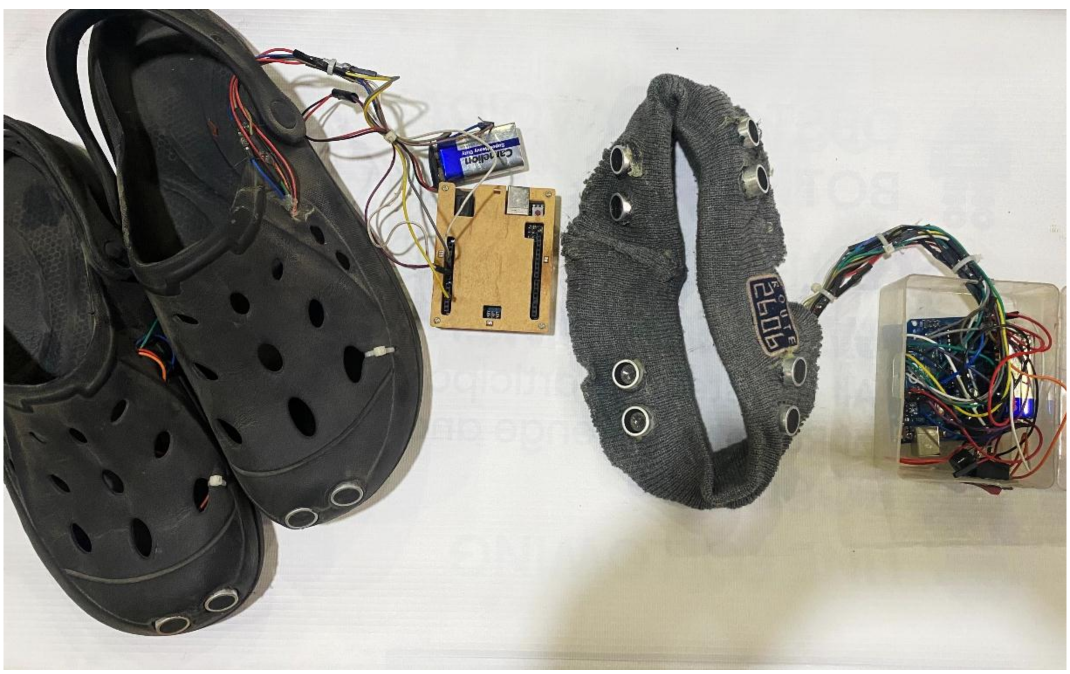

Figure 5. Prototype of the smart blind kit

That is a carefully weighed functionality, ergonomics and portability that is implemented in this hardware device. A full picture of the user space is possible due to the combination of both foot-level and head-level sensors, and the lightweight, portable and wearable device design can guarantee user mobility and comfort. The system was physically tested successful with reasonable test in indoor area as well as outdoor environment. A physical pre-prototype of the smart blind kit was able to be built and tested. The example of the device, as it is presented in Figure 5, is two sandals that have been modified to include ultrasonic sensors at frontal toe facet to sense near ground objects, stairs, or abrupt fall. The sensors are plugged together by insulated wires to a centrally placed central control that is within a transparent plastic casing with Arduino Uno board, voltage regulator circuit, and RF circuit. Alongside the foot-mounted sensors, a fabric headband provides infrared (IR) sensors located at different angles (left, front, and right) to help identify lateral and frontal detection of obstacles at an adult upper-body height. A small size of powers supply module of 9V battery is externalized and attached to the system through a safe power bus. The jumper connectors are used to design the wiring so that maintenance is easy, and pluggable so that they are modular and upgradable in future. That is a carefully weighed functionality, ergonomics and portability that is implemented in this hardware device. A full picture of the user space is possible due to the combination of both foot-level and head-level sensors, and the lightweight, portable and wearable device design can guarantee user mobility and comfort. The system was physically tested successful with reasonable test in indoor area as well as outdoor environment.

In the obstacle introduction tests, ultrasonic sensor (HC-SR04) was evidently true at consistency level in objects positioning at a distance between 20 cm and 250 cm. The error margin of the distance measurement was found to be less than 3% in an average with regard to non-contact obstacle alert systems. Even the buzzer had a response time that took almost nothing and there was audio feedback by the milliseconds as the buzzer went off immediately an obstacle was detected. The rate of the beeping signal significantly indicated the level of proximity- the patients indicated that the rate could easily tell when obstacles are far or near without the need of resetting the mind in terms of reaction. Based on controlled light environments, the IR sensors that were placed on the headband and on the hand stick could sensibly sense the presence of obstacles laterally to a certain degree of precision. Nonetheless, under outdoor daylighting conditions, when there is a lot of sunlight, the infrared sensors were slightly unstable with infrared interference being another recognized weakness in IR tech. However, they worked well in low light indoor environments and alerted the user concerning other objects to the side, including walls, furniture, and humans. The RF locator capability was also put to test by deliberately losing the device in a room. When the RF transmitter key is pressed, the buzzer responded instantly so that the user can know the location of the device through auditory signals. This functionality was beneficial and especially valued by those who took part in testing since visually impaired people usually find it hard when they lose their tiny tools or devices. Power consumption was 70 to 90 mA average during constant use on a 9 volt alkaline battery, which gave ca. 6 to 8 hours. It consumed low power and this was due to the use of minimal components and lacked display units as well as heavy peripherals. Moreover, the form factor of the system that constitutes a lightweight PVC stick and flexible plastic headband, allowed the user to dress and operate the device comfortably and without getting tired.

The user feedback on the system was taken through the informal usability sessions involving a few visually impaired users and their peers. Responding users stated that the audio feedback proved to be useful and did not overload them. The device was believed to be easy to get accustomed to, worth the use, very intuitive to use, and a promising alternative to conventional white canes. Others argued that voice instruction or vibration as another modality should be incorporated to allow the accommodation of various user preferences or in a noisy environment. Although it is effective, some limitations were noticed. This system is bound to a few limitations in as far as the speed at which an object moves as well as the type of object is concerned since it only detects the object through proximity. It also does not have GPS or voice command capabilities that may improve work in complex outdoor environments. These were observed as the possible developments in newer versions. In general, all of the outcomes demonstrate that the smart blind kit has captured its main goals (namely, to ensure real-time, reliable, and low-cost obstacle detection and feedback to visually impaired users). It is simple, cheap and modular, which makes it a good candidate to be deployed on a large scale in the developing world where no assistive technology is usually available.

Conclusion and Future Work

In this paper, we have shown the effective design, construction, testing of the Smart Blind Kit, a wearable assistance device, which is supposed to help a visually impaired easier movement and awareness of the surrounding world. The invention utilized readily available and inexpensive devices, such as ultrasonic and IR sensors, an Arduino Uno microcontroller, an RF-based locating system and auditory feedback mechanisms. The system will offer real-time obstacle detection with vibration module and proximity warnings using a buzzer thus the user will be able to explore platforms both indoor and outdoor settings with a lot of confidence. In order to prove the feasibility of a suggested solution, the fully functioning hardware prototype was created. The prototype, as seen in Figure 5, consists of sensor-integrated sandals, a head-mounted IR-based sensing unit, a processing box that contain the central Arduino, and a RF locator module with battery power. The headband facilitates upper-body and lateral obstacle perception and the sandals ground-level obstacles and drop-offs providing complete spatial coverage. The ergonomics and functionality of everyday use is provided by the wearable design. Also, schematic circuits of both modules were developed in detail. Figure Y shows the diagram of the headband circuit and six ultrasonic sensors are connected to Arduino through a breadboard to provide wide-angle coverage of obstacles. Figure Z shows the circuit of sandals, this circuit consists of an ultrasonic sensor and 2 IR sensors connected with Arduino and buzzer and a rechargeable power supply. These plans confirm the design as being modular and scalable, which makes it easy to improve or copy it in the future. This system was proven on variety of different scenarios and the findings were that this system gives high accuracy on detection of obstacles, quick response time and minimal consumption of power. The users liked the simplicity and easy to use part of the device and the adaptive alerting mechanism that is present in the buzzer and the easy use of the practical RF locator. In spite of these good things, there are some limitations associated with the current version. It does not offer higher-level capabilities as GPS-based navigation, vibrating feedback or voice-managed communication that might provide a better usage experience in higher familiarity conditions or a noisy setting. Some interference also occurred with IR sensors in very high sunlight that demonstrated minor inconsistencies- an improvement that can happen in the future. Planned future improvements include enabling GPS modules, voice recognition, Bluetooth connection to pair with smartphone connection, and a vibration motor that can be used to switch between various types of feedbacks. Reformulation of the enclosures to add wearability, water resistance and a longer battery life, are also in the pipeline. Moreover, the move of the breadboard to the use of custom PCB design will enhance the durability and allow commercial scalability. Finally, the Smart Blind Kit shows us that low-cost, embedded electronics are becoming useful and scalable solutions to assistive mobility. As it continues to be developed further, the device has the potential to become an instrumental component in enhancing the self-reliance and safety levels of the visually impaired- particularly in low-resource societies.

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