Development of Obstacle and Pit-Detecting Ultrasonic Walking Stick for the Blind

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Abstract - This project focused on improving mobility for a blind person by creating an obstacle and pit detecting walking stick using ultrasonic sensors. The project comprised of both hardware and software. The hardware consists of ultrasonic sensors, buzzers and a microcontroller, while the software consists of Arduino Integrated Development Environment (Arduino IDE), which was used to program the microcontroller. A Polyvinyl Chloride (PVC) casing was used to house the hardware components. The ultrasonic sensor that detects obstacles was programmed to detect obstacles at a distance of 100 cm or below and causes the buzzer to sound so as to alert the blind person. Another ultrasonic sensor was programmed to identify pit at a depression of 18 cm and above. This stick was tested to detect obstacles by 80 different blindfolded individuals within a room with different objects placed at different positions. Results showed that the percentage reduction of collision rate when comparing the developed ultrasonic walking stick to a normal white cane is 90.1%. This shows that the ultrasonic walking stick is reliable for domestic use by a blind person.

Keywords— Arduino, ATmega328 Microcontroller, Blind walking stick, Mobility aid, Smart cane, Ultrasonic sensor.

1 INTRODUCTION

The World Health Organization (WHO) indicates that there are about 180 million blind and partially sighted people in the world, of whom 90 per cent live in developing countries (Muanya, 2015). Nigeria has an estimated 4.25 million moderates to severe visually impaired or blind people (Kyari et al., 2009). The most common diseases that lead to blindness are cataracts, retinal diseases, diabetic retinopathy, macular degeneration, retinal dystrophies, uncorrected refractive errors, corneal diseases, Retinitis Pigmentosa and glaucoma (Kehinde & Ogwurike, 2005; Muhammad et al., 2010). As the number of blind individuals continues to grow, the need for continuing interventions that could help them achieve independence in movement with some amount of ease increases likewise (Kim & Cho, 2013; Vera, Zenteno, & Salas, 2014).

Blind people have been able to move independently, safely, and confidently with the use of common tools like the white cane (Kim & Cho, 2013), guide dogs (Faria, Lopes, Fernandes, Martins, & Barroso, 2010) and their children who are usually deprived of going to school (Kuyini & Alhassan, 2016). Blind people swing the white cane some distance around their feet to detect the existence of an obstacle on their path , while a guide dog is trained to guide their master to avoid all obstacles, as well as help them in going up and down the staircase; both have their limitations (Faria et al., 2010). The cane can only detect obstacles when it has contact with one and may be unable to tell if an obstacle exists some distance away (Kim & Cho, 2013), hence unable to warn the user when there is an obstacle in their path until the user has touched it. In some cases, blind people are seriously injured when obstacles are not sensed and their mobility is limited if they cannot understand their environment (Chaccour & Badr, 2016). The conventional white cane poses a much disadvantage to a blind user especially in unfamiliar terrains, as it does not have a navigation technology to enable a user to navigate such successfully (Pyun, Kim, Wespe, Gassert, & Schneller, 2013).

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Considering the limitation of the traditional white cane, research and development groups have focused on assistive technology (AT) (Roseli, Aziz, & Mutalib, 2010) like the smart cane in this case and other devices for various kinds of impairments (Chaccour & Badr, 2016; Dang, Chee, Pham, & Suh, 2016; Gurkan & Akan, 2014; Gurung & Branch, 2015; Kumar, Patra, Manjunatha, Mukhopadhyay, & Majumdar, 2011; Lakde & Prasad, 2015b; Selvi, Kamath, & Sudhin, 2008; Uddin & Suny, 2015). The principal components of most smart canes are ultrasonic sensors, infrared sensors, laser sensors and audio assistance or vibration to increase the mobility of the blind (Lakde & Prasad, 2015a).

In the early 90s, a largely successful electronic talking stick was designed to instruct a blind individual to walk and go up and down the stairs. It also had the capacity to tell dangerous depressions in the road, and the ability to call for help when the blind person falls (Chi-Sheng, 1992). However, it was made of scanning devices and a control box, which meant it was far from being simple and cheap. Recent studies have established that smart sticks for assisting the navigation of a blind user can be achieved using simple ultrasonic sensors and could detect obstacles within a range of 2 - 4 meters (Muhammad et al., 2010).

Normal ultrasonic sensors and ATMEL microcontroller were used to construct a foldable smart stick with rechargeable features (Kang, Kim, & Moon, 2001). This was dependent on the principal property of sound's reflection as a form of wave (Amusa et al., 2018). Frenkel (2008) used a pulse of ultrasound range of 21 KHz to 50 KHz which hit a hard surface to generate echo pulses. By calculating the difference between signals transmitted time and signals receiving time, the distance between the user and the obstacles was predicted. This system was very sensitive in terms of detecting obstacles, had a detection range of up to 4 meters and a detection angle 0 to 45 degree. However, this system required more power to operate because of the transmitter and receiver circuits.

Damdhare and Sakhare's (2011) system operated using obstacle detection principle, GPS technology and voice circuit with a camera fitted to a person's head. The camera used an algorithm to identify elevations and obstacles in front of the blind person and ultrasonic sensors to detected obstacles. The system had a disadvantage of being complex and may hinder adherence. Koley and Mishra (2012) designed a voice-operated outdoor navigation system equipped with GPS, ultrasonic sensors, an SD card and ARM processor. The device focused on external navigation without the capacity to effectively work indoor and needs improvement in the accuracy of the GPS.

Also, the highly revered UltraCane™ used ultrasonic waves from two sensors to detect street furniture and other obstacles within 2 or 4 metres. It also had the capacity to give tactile feedback to the user via their thumb placed over two vibrating buttons on the handle of the stick (Hoyle & Waters, 2008; Sound Foresight Technology Ltd, 2003). It, however, lacked the capability to detect pit and also came at a very expensive price of £635.00 (N304,092.00). Also, there exists the SmartCane™ as a cheap alternative to UltraCaneTM championed by Balakrishnan in India (Senthilingam, 2014) and the water and obstacle detection smart walking stick (Gbenga, Shani, & Adekunle, 2017) but these also have the inherent limitation of the inability to detect pit as the preceding innovation.

Therefore, this work aimed to develop a simple and low-cost ultrasonic walking stick with the ability to detect obstacles and pits to enable quick response to obstacles and depressions in the path of a blind person and evaluate the performance of the intervention.

2 Methodology

2.1 Materials Used

Table 1 presents the list of components used in developing the low-cost ultrasonic walking stick for the blind and their associated costs.

2.2 Construction

The construction is divided into three sections 1) Pre-construction, 2) Major construction and 3) Packaging.

a) Pre-construction

Pre-construction was carried out mainly to ensure that faulty components are easily identified so they could be easily replaced before the major construction could be carried out. During the pre-construction stage, a circuit diagram was simulated to determine the effectiveness of the circuit, the circuit was then assembled on a breadboard to determine its efficiency and to determine the functionality of the system before arranging it on the Printed Circuit Board (PCB). The installation of the IDE software and programming was done. This involved connecting the laptop which contains the IDE software to the microcontroller with the aid of a USB cord. The code for controlling the entire hardware was written and then burnt into the memory of the microcontroller. The algorithm of the program allowed the system to be controlled by two sets of instructions; one aspect of the instructions allowed ultrasonic sensor to detect obstacles within the range set of 100 cm or below, being the average step length (75 cm) for men (Pachi & Ji, 2005) with 25 cm factor of safety, and upon which the ATmega328 microcontroller directs the program and instruction to the buzzer. The second aspect of the instruction allowed the other ultrasonic sensor to detect pit within the set range of depth above 18 cm and above. 18 cm being the maximum recommended riser height in staircase design which relates to human step uplift (Liu, Wang, Ma, & Li, 2005). A step down from a height above this distance becomes uncomfortable and is hereby recognized as an indentation in the surface of the walking plane known as the pit.

b) Major construction

After a satisfactory test of the assembled components on the Breadboard, the components of the circuit were transferred to the Printed Circuit Board (PCB) and proper soldering of all components on PCB was carried out, to ensure that the soldered joints were electrically continuous and mechanically strong.

Table 1. Components and Costs for the smart cane

S/NO	ITEMS	Quantity	Unit Cost (N)	Amount (N)
1	Arduino UNO board with ATmega328 microcontroller	1	4,500.00	4,500.00
2	Arduino IDE software using Arduino C programming	1	4,000.00	4,000.00
3	Two [HC-SR04] Ultrasonic sensors	2	1,500.00	3,000.00
4	Buzzer	2	1,200.00	2,400.00
5	Ceramic capacitors	2	140.00	280.00
6	PNP type resistor	1	40.00	40.00
7	LED	1	500.00	500.00
8	LM7085 Voltage regulator	1	600.00	600.00
9	Switch	1	200.00	200.00
10	9V Battery	1	500.00	500.00
11	PVC pipes	1	2,000.00	2,000.00
			TOTAL	18,020.00

c) Packaging

A casing, 15 x 9 x 4 cm, made of PVC was used to house the mobility system circuit, having holes in front and beneath the casing for the insertion of ultrasonic drums to allow them to emit and receive radiation. The mobility system casing was mounted on a PVC covered light wooden stick 90 cm long and 2 cm thick with a handle dimension of 23 cm by 2 cm. The switch was placed at the top of the handle of the stick to turn the circuit ON and OFF. The AutoCAD drawing of the smart walking stick is presented in Figure 1(a) and the constructed system is shown in Figure 1(b).

(a) (b)

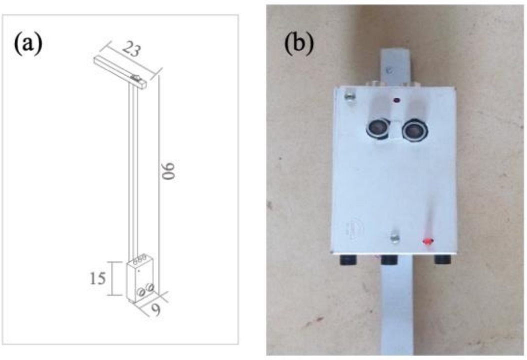

Fig. 1: (a) The designed smart walking stick (b) The constructed

2.3 Circuit Diagram

The circuit consists of a switch, 9V battery, two capacitors, a voltage regulator, ATmega328 microcontroller, a Light emitting diode (LED), three buzzers and two ultrasonic sensors. The Battery supplied the necessary voltage to the circuit for the components to work. The circuit diagram, Figure 3 shows the microcontroller, the buzzers, the LED and the two ultrasonic sensors connected in parallel to one another which meant they drew the same amount of voltage. From each component's datasheet, the maximum voltage required by individual components is 5V respectively. Therefore, the 9V battery was regulated by LM7805 to regulate voltage from the power supply to 5V. The voltage regulator is normally used either with or without capacitors usually 0.33 and 0.11 depending on individual choice when used in regulating direct current. The overall circuit diagram for the mobility system is shown in Figure 2.

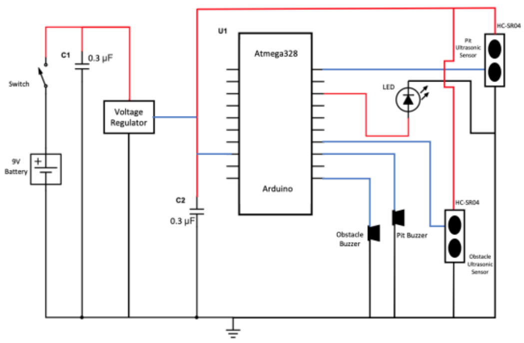

Fig. 2: Mobility System Circuit Diagram

2.4 Obstacle and Pit Detection System

The Obstacle and Pit detection system was designed using ultrasonic sensors. Implementation of obstacle and Pit detection system in the smart cane is important as it is used to detect obstacles and pits below knee level of blind persons. To achieve this, ultrasonic sensors were combined with microcontroller and Arduino for controlling the system. The flowchart of the obstacle and pit detection is shown in Figure 3(a) and (b).

The operation starts when HC-SR04 receives a high pulse and hence initiates the sensor. At every instance, eight cycles of ultrasound at 40 kHz is sent to detect the presence of an obstacle, the distance in centimetres can be calculated using equation 1, which is given as:

$$\text{Distance} = \frac{\text{Time}}{58} \text{ in cm} \qquad (1)$$

Time width of the echo pulse is measured in µs (microsecond).

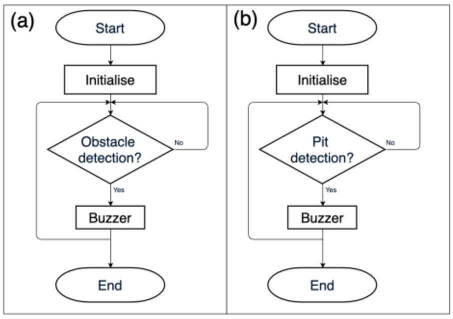

Fig. 3: Flowchart for (a) obstacle detection and (b) pit detection

Obstacles and obstructions are detected by the front facing HC-SR04 Ultrasonic sensor module, which releases a periodic 8-cycle burst of ultrasound from its transmitter drum in its front facing direction. Once the transmitted ultrasound hits an obstruction, the ultrasonic wave gets reflected back to the HC-SR04 module and the reflections are picked up by the receiver drum. The pit detection system of this smart walking stick consists of a downward facing HC-SR04 that releases a periodic 8-cycle burst of ultrasound from its transmitter drum in its downward facing direction. Once the transmitted ultrasound hits the ground, the ultrasonic wave gets reflected back to the HC-SR04 module and the reflections are picked up by the receiver drum. The microcontroller keeps watch on the time it takes the ultrasound to travel to and fro; using the pulse in function in Arduino C. With the travelling time known and also taking the speed of ultrasound in air to be 340 m/s, the range can be easily obtained by simply relating velocity, displacement and time. Hence the range (distance) is given by equation 2.

$$\text{Range } \mathbf{R} = \left(\frac{\text{Total displacement}}{2}\right) \qquad (2)$$

The value of the displacement obtained is used by the program to determine the presence or absence of obstructions or pit. This design uses a threshold value of 100 cm which is the highest value of distance that would be judged as an obstruction and threshold value 18 cm which is the lowest value of depth from the sensor tip to the ground that would be judged as a pit. This implies that object distance that is equal to or less than 100 cm would infer the presence of an obstacle and any value of displacement that is equal to or greater than 18 cm would infer the presence of a pit, any of which would immediately trigger the buzzer to produce a sound of high pitch and high frequency. The buzzer, once triggered ON, would remain so until the obstacle is cleared or avoided. The block diagrams of the obstacle detection and pit detection systems are given in Figure 4 (a) and (b) respectively.

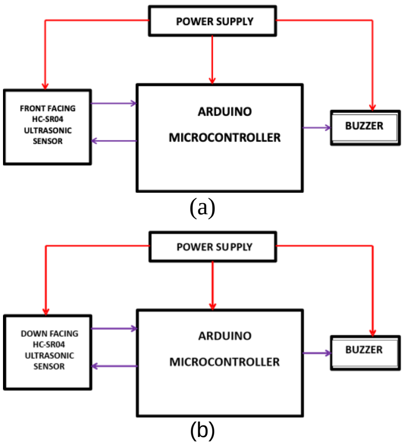

Fig. 4: Block diagram of (a) Obstacle detection system and (b) Pit detection system block

The model of the ultrasonic sensor used in this design is the HC-SRO4, it provides 2cm - 400cm non-contact measurement function, and the ranging accuracy is about 3mm. The modules include ultrasonic transmitters, receiver and control circuit. The features of the ultrasonic sensor are described in Table 2.

Table 2. Features of Ultrasonic Sensor [HC-SRO4]

Working voltage	DC 5V
Working current	15mA
Working frequency	40Hz
Max range	4m
Min range	2cm
Measuring angle	15°
Trigger input signal	10 µs TTL pulse
Echo output signal	Input TTL lever signal and the range in proportion
Dimension	45 x 20 x 15 mm

2.5 Testing

Series of testing was carried out on the system before and after packaging. These tests were divided into two:

1. Pre-testing i.e. before packaging: This was the first test that was carried out on each component during the pre-construction stage with the use of testing tools like multimeter to check whether the rating specified by the manufacturers were correct or not. Continuity test was also carried out on components before using.
2. Post-testing i.e. after packaging:

a) Obstacle detection: The microcontroller was programmed with the use of IDE software to detect obstacles at various distance from 0 to 60 cm with an increased interval of 5 cm. The system was then exposed to objects at the same distance programmed, the distance at which the system sensed the object was noted and compared to the programmed distance.

b) Pit detection: The designed smart walking stick was meant to respond to pits of various depths, achieved by simply increasing the height of the ultrasonic sensor used as pit detecting sensor to the ground.

c) Collision rate: The collision rate for both traditional cane and Ultrasonic sensor was carried out, and the average collision rate was obtained under the same time interval. This was performed within a room with different objects placed at different positions and in which a person was blindfolded and asked to move around within the room. Firstly, with the white cane and then followed with the use of the smart cane. This was repeated for 80 users and it was ensured that the obstacles were rearranged in each case. The pair test between normal cane and the smart cane was randomized so as to ensure that the participants do not have any chance of memorizing the positions of the obstacles at any instance. The collision rate was calculated using equation 3.

$$\text{Collision rate} = \frac{total\ number\ of\ collision}{time\ interval} \qquad (3)$$

d) Response to various objects: Experiments on how the stick responded to different surfaces were also carried out. The stick gave a sound when it approached any obstacle placed in front of it within the range of 100cm. This was used to demonstrate the object that the smart cane would likely always respond to effectively.

3 Results and Discussion

The components were found ok for usage and the program also responded as intended. The construction was carried out and the system was packaged as shown in Figure 1 (b). After the construction and packaging of the system, tests such as obstacle detection, pit detection, collision rate and response to various objects were carried out.

3.1 Obstacle Detection

The distance from the obstacle at which the sensor responded to the obstacle was measured and the mean value of error in the response between the actual measured value and sensor response value is -1.154 as given by Table 3. Hence, this meant that using the stick to detect obstacles was reliable even though no further test was carried out to check what caused changes in the sensor's response value at some distance

Table 3. Result of sensor-detected distance and measured distance

No.	Measure Distance (cm)	Sensor Detected distance (cm)	Error (cm)
1	0	0	0
2	5	3	-2
3	10	9	-1
4	15	14	-1
5	20	18	-2
6	25	25	0
7	30	28	-2
8	35	33	-2
9	40	39	-1
10	45	45	0
11	50	48	-2
12	55	54	-1
13	60	59	-1
	Average error		- 1.154

3.2 Pit Detection Test

The stick detected various pit depth at specified distances between 0 – 60 cm at an increasing interval of 5 cm. The mean value of error obtained between the ultrasonic sensor response to the actual measured distance was very small at -0.384 cm. Hence, this shows that using the stick to detect pit was reliable. Table 4 shows the differences between ultrasonic sensor measurement and actual measurement for the pit.

Table 4. Result of Sensor detected distance and measured depth

No	Measure Distance (cm)	Sensor Detected distance (cm)	Error (cm)
1	0	0	0
2	5	4	-1
3	10	10	0
4	15	14	-1
5	20	19	-1
6	25	25	0
7	30	29	-1
8	35	35	0
9	40	40	0
10	45	45	0
11	50	49	-1
12	55	55	0
13	60	60	0
	Average error		- 0.384

3.3 Collision Rate Test

When using the traditional cane, the users collided with 38.4 ± 2.8% obstacles on an average of 80 trials carried out by blind folded users. The ultrasonic walking stick reduced the collision rate to 3.8 ± 0.9%. This represents a drastic reduction of 90.1 ± 2.4% when using a smart cane compared to the traditional white cane. Table 5 shows the comparison between the number of collisions of a typical white cane and the developed ultrasonic walking stick.

Table 5. Collision Rate (Number of collisions per session)

	Normal cane	Smart cane	Percentage reduction in collision rate %
All obstacles	38.4± 2.8%	3.8± 0.9%	90.1± 2.4%

3.4 Response to Various Object Test

From Table 6, it was observed that the smart cane responded more accurately to the concrete wall compared to other objects. This implies that the ability of the smart stick to detect obstacles like a concrete wall will be more reliable compared to plastic, cardboard and human body respectively.
Although the stick performed well in all cases with average accuracy above 90% detecting surfaces at a distance of 100 cm, it is superior in detecting the presence of a concrete wall.

Table 6. The response of stick to various objects at a distance of 100 cm

Object	Test 1	Test 2	Test 3	Test 4	Average Accuracy
Concrete wall	99.8	99.9	100	100	99.95
Human body	90.0	84.6	92.2	95.5	90.58
Cardboard box	97.2	90.3	92.2	95.5	94.0
Plastic	92.3	94.2	98.1	90.0	93.65

4 Conclusion

The design of a low-cost obstacle and pit sensing smart walking stick for the blind was achieved using simple technology and the various test carried out show that the stick is reliable in sensing obstacles and pit. The percentage error obtained was very small (i.e. -1.154% and - 0.384%) when the smart cane was used to detect obstacle and pit respectively. Also, other results obtained shows that smart cane ensures low collision rate with objects by reducing the collision rate by about 90% when compared to the traditional white cane and was able to give a high response to obstacles of different materials that the blind are likely to bump into.

The development of this technology can be furthered by the following suggestions:

1. The accuracy of the obstacle detection can be increased by ensuring the improvement of the sensitivity of the ultrasonic sensor and buzzer.
2. The ultrasonic sensor can be made to be adjustable in order to detect fast moving objects.
3. Water sensors can be incorporated for detection of water on the floor instead of only obstacles and pits.
4. Two ultrasonic sensors can be placed in the front, one for detecting obstacle below the wrist waist and the other one for detecting obstacle above the wrist waist.
5. Vibrating motors can be used to replaced one of the buzzers to distinguish what was being detected.
6. A foldable walking stick could be made to decrease the smart cane's size and ensure portability

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