Design and Fabrication of A Portable Obstruction Detection Device For Visually Impaired Persons

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Abstract
The cow-horned cased Obstruction Detection Device (ODD), powered by 9V battery, is designed for visually impaired persons. It is constructed using two HC-SR04 ultrasound sensors for front obstacle and depression detections. The device detects an obstacle by emitting ultrasonic sound that hits the interface and interprets the echo. The emission of this sound is triggered by the PIC16F877A microcontroller programmed to send out feedback to the user's earphone in form of a musical note peculiar to the range of distance of the obstacle. The device is integrated with Radio Frequency (RF) Module that locates the device when misplaced. This Module has LM555 timer that regulates the signal emitted by the misplaced device. The device is incorporated with a Light Dependent Resistor (LDR) that detects any change in illumination. This project designed and fabricated a cheap locally cased ODD with comparative advantages of informing the visually impaired of the range of distance and position of the obstacle and the location of a misplaced device.

Key word: Visually Impaired, HC-SR04 ultrasound sensor, Obstruction detection

1. Introduction

Visual impairment (VI) is a health condition that greatly affects individuals with little or no recognition of tiny details using their normal human eyes. [1] "Blind people are those individuals bearing the visual acuteness of 6/60 or the horizontal range of the visual field with both eyes open that are less than or equal to 20 degrees". Nowak reported that an estimate of more than 60 million people across the globe are impaired of visual characters with over 10% of the estimated figure mentioned above are completely blind where as 90% have low vision. This estimation was given by World Health Organization (WHO) in 2011[2].

Echoes in the natural environment sometimes serve as a great tool for some blind people to notice anything or change in the immediate environment (passive) whereas the remaining ones use echoes from the mouth clicks to obtain information (active) [3]. Both passive and active means play significant roles towards teaching the visually impaired individuals more about their environments. This could be termed as human echolocation [3]. Human echolocation has been effectively and efficiently applied in the past but yet, it still does not help the visually impaired victims' mobility to the fullest. Improvement in obstacle detection (OD) and warning such as developing obstacle detection devices (ODDs) have and may still help these victims' mobility. Several attempts have been made to produce modified ODDs for the visually impaired using some components with limited number of applications. Among many constraints faced by a blind person, the challenge of independent mobility and navigation is eminent. An efficient reintegration of the disabled people in the family and society should be fulfilled; hence it is strongly needful to assist their diminished functions.

Electronic Travelling Aids (ETAs) help in guiding and relieving much stress from visually im-

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paired pedestrians and current advancements in embedded systems have opened up a vast area of research and development for affordable and portable assistive devices for the above mentioned individuals. At the moment, the available assistive devices to detect obstacles for sale help to alleviate the cause of such medical problem and also make their lives easier and safer but unfortunately, cost as well as size of devices, intrusiveness and higher learning curve prevent the visually impaired from making good use of these available devices. Researchers haves been and are still working to make the device lighter, portable, safe and cost effective for better service [4].

More recently, ETAs bearing sensors and sound systems are designed for improved navigation of blind people. In this study, an advanced ETA with advanced technology like ultrasonic sensors for obstacle and depression detection &radio frequency (RF) module were considered to allow visually challenged people to navigate properly. This research project focused on modifying the already existing ODD with attractive features.

1.1 Blindness and Visual Impairment Survey

In Nigeria, national blindness as well as visual impairment survey was carried out between 2005 and 2007, and a unique randomly cluster sampling was used with probability proportional-to-size techniques to knock out the non-cross-sectional, nationally population sample from over 10,000 individuals above 39 years across the entire country [5]. More than 1.12 million people from 40 years above have lost their sight in Nigeria and over 2 million of the above mentioned age groups have moderate visual impairment as reported by. [6] Also employed methods to generate estimates on the prevalence and causes of blindness in Nigeria. This could result from one or two of the leading causes of vision impairment in existence such as uncorrected refractive errors, cataract, age-related macular degeneration, glaucoma, diabetic retinopathy, corneal opacity, trachoma and many more[7]. Also reported that more than 75% of the entire vision impairment in the globe could be prevented and the most prevalent are individuals more than 50 years. Vision has been found to be a delicate and relevant aspect of human physiology as our sight aids in giving human beings more than 79% information from the environment [8]. Modern walking aids are designed to be portable and dynamic to be faced or pointed in various directions for obstruction detection and give mobility assistance to blind and partially-sighted people by emitting ultrasonic waves, just like the echolocation system that are used by bats and dolphins[9]. The time takes for echo to occur is determined from an emitted ultrasonic pulse by bat. By its implicit knowledge of the velocity of sound in air, the distance travelled by the sound is able calculate the distance to the object.

This knowledge will be mimicked and apply to walking aid design to work in a similar way for safety purposes. The walking aid has some ranges such as short or long range modes to choose from which senses obstacles within 350cm from the handle. Device assists the VI person to move around his environment while making wise decisions quickly and confidently. An electronic component, the sensor which has already been used by researchers posed potential vibes as well as risks in the past, however, a more dynamic one, the ultrasound sensor well considered and recommended for this research has emitting and detecting potentials as well as good response to environmental noise and interference.

1.2 Sound Wave and Echolocation

Sound wave propagates by longitudinal motion (compression/expansion) rather than transverse motion (side-to-side) and can be modeled as weights connected by springs. Ultrasound waves travel at a speed of sound © can be determined using equation (2.1) as reported by [10]

$$c = \sqrt{1/pk} \qquad (2.1)$$

where k is compressibility and p is the density of a material.

Human echo location popularly known as "facial vision" or "obstacle sense" was introduced by a zoologist; Donald Griffin in 1940s which believed in proximity of objects resulted to change in skin pressure [10]. Meanwhile, reports related to blind humans that can locate silent objects began in 1740s [11]. In the 1940s, experiments performed in the Cornell Psychological Laboratory revealed that sound and hearing, rather than change in skin pressure were found to be the mechanisms driving agent [11]. Echolocation is also defined as the production of sound used for communication and could also be seen as the use of ultra-high frequency sounds for navigation and locating prey. The field of human and animal echolocation was surveyed in book form as early as 1959 [12]. Bats and marine mammals are able to use sound to "see". It is the returning echo that gives the animal an "image" of some parts of its environment.

Echoes must be loud enough to return to the animal and short enough so that the echo of the sender returns back to the animal or human before the next one is sent out. Echolocation is used by mammals like dolphins, whales and bats. Humans have also learned this ability to interact with their environment when they are blind. The term was created by Donald Griffin, who was the first to conclusively demonstrate its existence in bats [12].

1.3 Ultrasound Wave

“Ultrasound” refers to frequencies greater than 20 kHz, the limit of human hearing. This type transmits waves into body which are reflected at the interfaces between bodies and the return time of the waves tells us of the depth of the reflecting surface[13].This was employed in 1942 as a diagnostic tool for localization of brain tumors, Ultrasound is used in Obstetrics and Gynecology to measure the size of the fetus to determine the due date, check the sex of the baby (if the genital area can be clearly seen), detect ectopic pregnancy, the life-threatening situation in which the baby is implanted in the mother's fallopian tubes instead of in the uterus and seeing tumors of the ovary and breast[13].

1.3.1 Ultrasonic Working Principle:

By measuring the time required for the echo to reach the receiver, we can calculate the distance. This is the basic working principle of Ultrasonic module to measure distance.

In ultrasonic module HC-SR04 as seen in Figure 2.2, we have to give trigger pulse, so that it will generate ultrasound of frequency 40 kHz. After generating ultrasound i.e. 8 pulses of 40 kHz, it makes echo pin high. Echo pin remains high until it does not get the echo sound back. So the width of echo pin will be the time for sound to travel to the object and return back. Once we get the time we can calculate distance using equation (2.2) from the speed of sound.HC-SR04 can measure up to range from 2 cm - 400 cm.

Recall that:

$$\text{Distance} = \text{speed} \times \text{time} \quad (2.2)$$

where speed of sound waves is given as 343 m/s.

So that the full distance can be evaluated from equation (2.3)

$$\text{Full Distance} = (343 \times \text{Time of Echo}) / 2 \quad (2.3)$$

Total distance is divided by 2 because signal travels from HC-SR04 to object and returns to the module HC-SR-04.

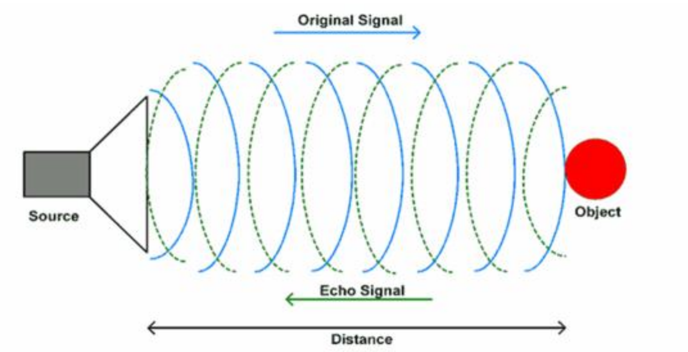

Figure 1: The working principle of Ultrasound (ElectronicWings, 2019)

2. Materials and Methods

2.1 Materials

The basic materials needed for this study were Vero board, 7805 voltage regulator, MX-FS03V RF transmitter and receiver module, cow horn, earpiece, LM555 timer, HYDZ buzzer, soldering iron and lead.

The electronic components required were ultrasound module HC-SR04 sensors, PIC16F877A microcontroller, resistors, capacitors, BC547 transistor, switch and connecting cables. A block diagram displaying the connection of the materials is shown in Figure 2 and the description of each material present in the block diagram was briefly illustrated in the next few subsections and figures below.

2.2 Methods

2.2.1 Systematic circuit analysis

This device was designed using some electronic components such as ultrasonic sensors connected to a microcontroller to measure distance. Processing of the series of measured distances is used to interpret to the visually impaired objects around him/her. A beeper was also connected to the system to emit audible sound which was used to locate the exact location of the device when misplaced. This worked with a portable wireless radio frequency remote control incorporated to the device. Different other sounds (tones) were used to indicate different operational behaviors of the design. This was achieved by emitting tones of different frequencies. Each sound (tone of unique frequency) indicated an operational status (for example when a porthole is found or when an object is in close proximity to the visually impaired person).

The system also detected night time using its LDR sensor in which output voltage of the sensor can be made to assist the blind person to know when it's dark. The device definitely needed to be portable and battery operated for easier and proper monitoring of the battery life span. This would enable the visually impaired know when the system battery is flat and needs replacement.

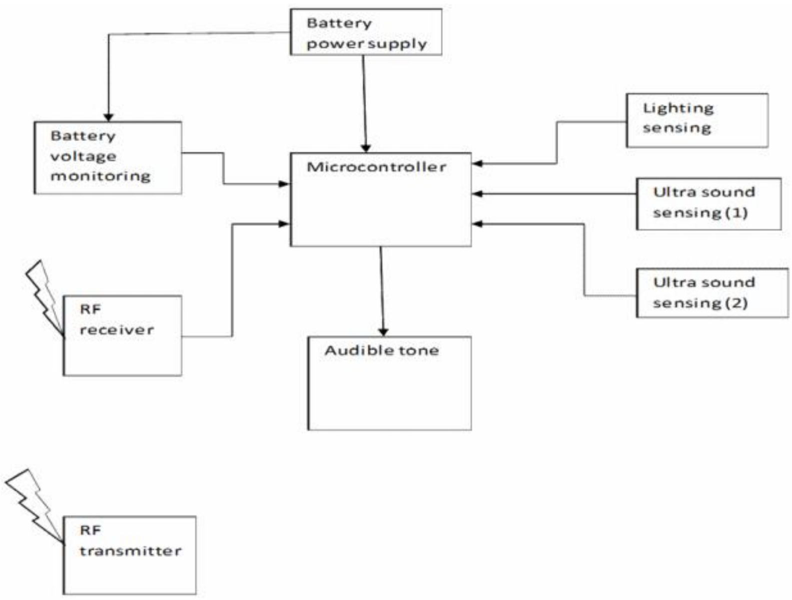

Figure 2: A Schematic Block Diagram of the Proposed System.

2.3 Battery

The device is energized by a 9v battery used for effective operation, and the device also senses low voltage below or at 6v and signal for replacement. This setup is made dynamic by including a monitoring feedback control by the microcontroller in the design. This was achieved by using a voltage divider with high value resistors that cannot consume more current as presented in Figure 3.

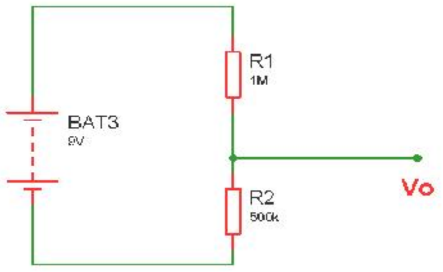

Figure 3: A voltage divider circuit

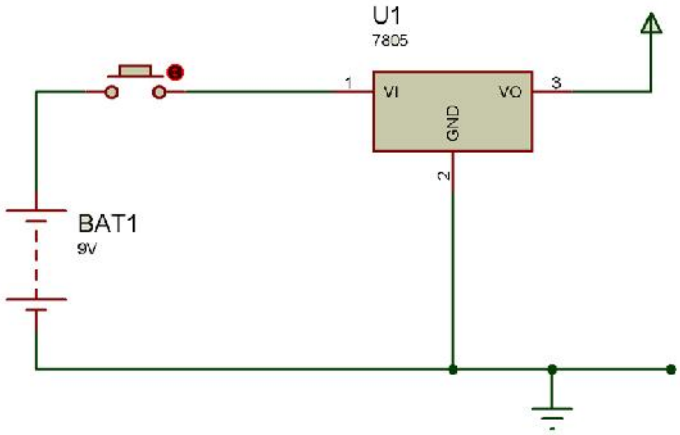

Figure 4: A circuit diagram showing how 5v is produced from 9v using the 7805 regulator (IC)

Also, this device works on 5v power supply but the battery is 9v. To provide the required 5v, the 9v from the battery is connected through a 7805 regulator Integrated Circuit (IC). This IC transforms the 9v to 5v power supply. That is; irrespective of the battery voltage it provides 5v as seen in Figure 4.

2.4 Beeper Frequency Design

Each audible tone received corresponds to a particular frequency while different tones correspond to different frequencies it allow microcontroller to operate within the time domain.

Frequency –time relationship is calculated as:

Frequency = 1/time ………….. (2.1)

Three (3) different frequencies was generated and used in combination to create distinct tones which are easily recognized. The frequencies are 4148 Hz (doo), 4695 Hz (ree) and 5278 Hz (mee) as in musical notes [14]. These frequencies are chosen following standard tone formation.

a) To generate 4148 Hz by the microcontroller, Frequency = 1/time and time = 1/frequency. Therefore, Time = 1/4148 = 0.00024108 seconds = 241.08 µseconds. The microcontroller must generate pulses of 241.08µs to get a tone of 4148Hz.

b) To generate 4695 Hz by the microcontroller, Frequency = 1/time and time = 1/frequency. Therefore, Time = 1/4695 = 0.000212992 seconds = 212.99 µseconds. The microcontroller must generate pulses of 212.99µs to get a tone of 4695Hz.

c) To generate 5278 Hz by the microcontroller, Frequency = 1/time and time = 1/frequency. Therefore, Time = 1/5278 = 0.0001894657 seconds = 189.47 µseconds. The microcontroller must generate pulses of 189.47µs to get a tone of 4148Hz.

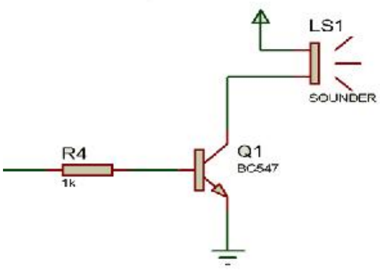

Figure 5: The beeper connection

Then, a microcontroller pin is then connected to the beeper in Figure 5 using a negative-positive-negative (NPN) transistor.

2.5 Radio Frequency (RF) Transceiver

The purpose of the RF signal in this work is to locate the misplaced device. The VI person shall have portable RF transmitter in the pocket. Since the walking aid has the RF receiver. To find the walking aid, the visually impaired will simply press a button on the RF transmitter of a coded remote. The RF receiver in the walking aid will receive the RF signal from the transmitter and pass the signal to the microcontroller. The microcontroller will interpret and emit a beep sound. The VI person will hear the sound move to the location of the sound and pick up his device.

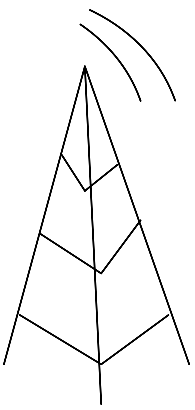

Figure 6: Schematic diagram of RF transmitter

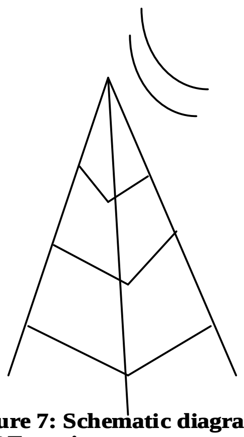

Figure 7: Schematic diagram of RF receiver

To achieve this, RF module "MX-FS03V" is used. This module comes as a pair – (the transmitter and the receiver). This module works using amplitude modulation technique. Its power supply is in the range of 3v to 12v. The technical specification of the transmitter is shown below.

It receives data to be transmitted serially and transmits them one after the other on a frequency of 433 MHz A typical example is displayed in Figure 6.

The receiver module compliments the transmitter module. It receives RF signal coming at 433 MHz as seen in the technical specification and Figure 7.

The output of this module connects to the receiving end of microcontroller.

2.6 LM555 Timer Design

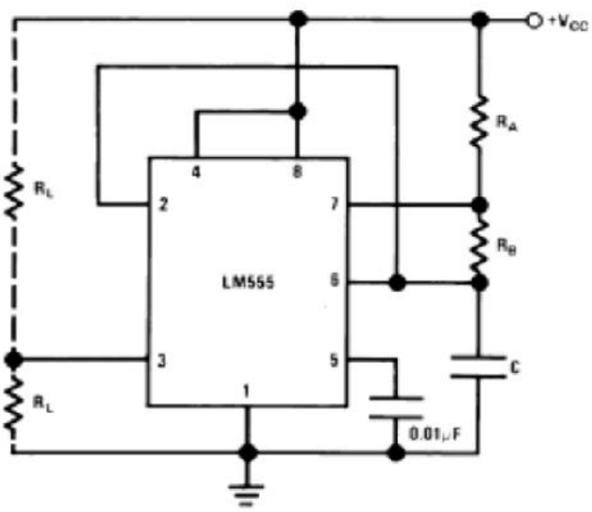

Figure 8: LM555 as an astable multivibrator (Jameco,

The transmitter of the RF module requires a pulsing signal to control data transmitted. This pulsing signal comes every second as specified in the technical data of the RF transmitter. Hence, a LM555 timer chip is used to provide this one second (1s) time pulsing. Figure 3.7 depicts the LM555 chip, an astable multi vibrator set at 1 second pulse.

The output of the LM555 timer is then connected to the RF transmitter. To achieve this LM555 configuration, the LM555 configuration formula is followed.

T = 0.693(RA+2RB) * C (3.4)

Since required time = 1 second, C = 10uf, RA = 47kΩ, then RB = ?

ie. RB = ((T/0.693C) – RA) / 2 = 48650Ω.

Therefore, RB = 48kΩ

2.7 Light Sensing with Light Dependent Resistor (LDR)

The LDR is a resistor whose value is influenced by the amount of light falling on it. When no light is falling on it, its resistance is highest. When it is exposed to light, its resistance drops. The LDR resistance is inversely proportional to the amount of sunlight falling on it. In the bright sunlight, the LDR resistance is 100Ω and in the night time, the LDR resistance is a minimum of 100kΩ.

To use this variation of resistance to work, we connect another resistor in series with the LDR to form a voltage divider. If we connect a 10kΩ resistor in series, the voltage divider so formed is thus displayed in Figure 9.

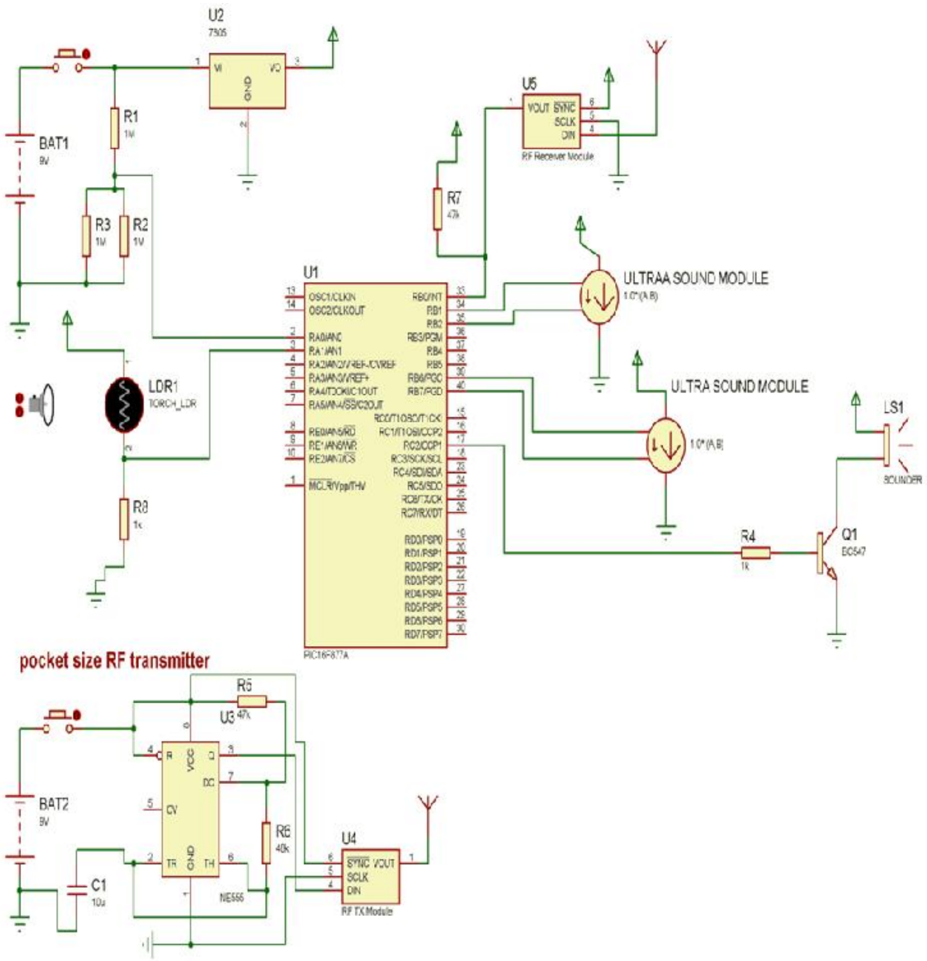

Figure 10: The Circuit Diagram

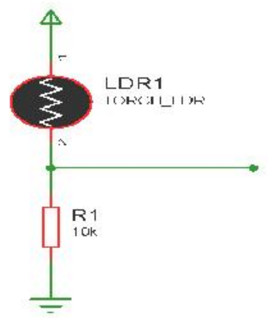

Figure 9: The LDR as a voltage divider

In the night (when there is no insolation), the output voltage will be as follows:–

(R1/(R1+LDR1)) x input voltage = output voltage

(10000/(10000+100000))x 5 = 0.455 volt.

In the day time when exposed to sunlight the output voltage will be :–

(R1/(R1+LDR1)) x input voltage = output voltage

(10000/(10000+100)) x 5 = 4.95 volt.

2.8 Microcontroller Specification /Hardware Connections

The microcontroller used is a PIC16F877A and this device has excellent features and capabilities. The specifications of this device comprise of its 8KB program memory size, 368B Internal RAM, I/O PINS= 33pins (5PORTS), 10 Bit ADC (8 channels), 3 Timers and 2 Comparators.

The two ultrasound modules used for this work are connected to PORTB. Battery level monitoring circuit is connected to one of the ADC inputs at PORTA. The RF module receiver is connected on PORTB. The beepers for audio aid to indicate different status/notifications of the device are on PORTC. These components are placed for convenient of easier assembling. The LM555 timer is connected to the RF transmitter module on a separate board in a separate housing. Figure 10 shows the system circuit diagram.

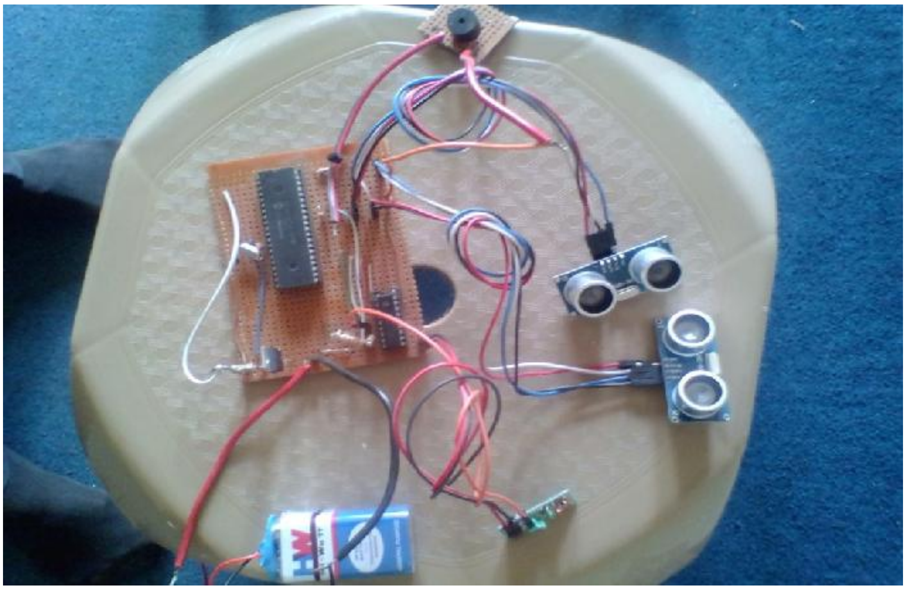

Figure 11: Components assembled together on a test bench

2.9 Hardware Implementation (Assembling)

All the hardware components required for the development of this device were purchased from the market and assembled together following the circuit diagram. The components include a cow horn, PIC16F877A microcontroller, 7805 voltage regulator, HC-SR04 Ultra sound sensor module, MX-FS03V RF transmitter and receiver module, LM555 timer, resistors, Vero board, capacitors , crystal, BC547 transistor, HYDZ buzzer and switch. A clear illustration is shown in Figure 11.

Figure 12: A cow horn case

The device is housed in a biodegradable and easy to handle cow horn in Figure 12.

2.10 Software Implementation

The software was designed to implement all the functionality of the module. The software must read the output voltage from the voltage divider so as to keep an eye on the battery voltage. It must initiate the ultrasound sensor module to send ultra sound pulses and by processing the returned echo signal, calculate the distance between an object/person from the sensor. The software must receive signal coming from the RF module receiver, process it so as to extract the correct transmitted bytes. It must finally generate the appropriate musical tones/notes used to communicate the situation to the visually impaired.

The programs are written in C++ programming language. It is written in MPLAB IDE. MPLAB IDE is used as the recommended development environment by the manufacturers of the PIC microcontroller.

2.11 System flow chart

Figure 13 depicts the schematic flow chart of the system.

2.12 The System Algorithm

The microcontroller initialized the input output pins, got the ADC ready, measured the battery voltage

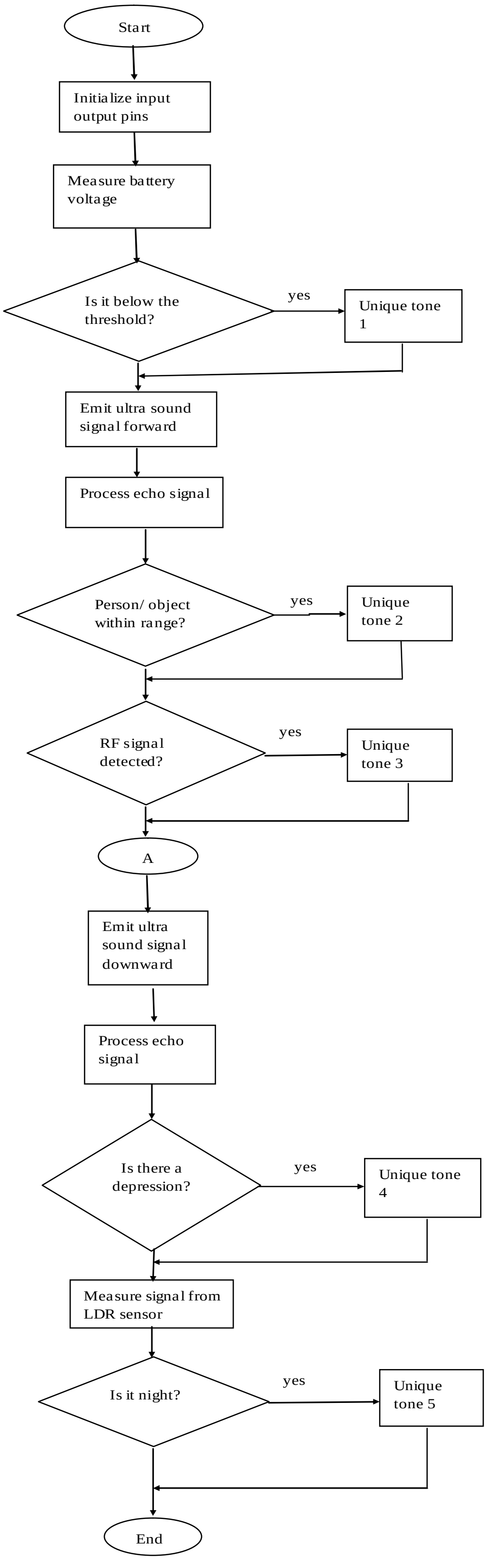

Figure 13: The system flow chart

and processed the measured voltage. Then, it signals the ultrasound module to emit ultrasound signal in the forward direction, processed the received echo information and calculated the range. If range is too close then sound the unique tone. Afterwards, the microcontroller read the RF receive module if valid bytes were received then sound unique tone and signals the ultra sound module to emit ultra sound signal in the downward direction, processed the received echo information and calculated variation in range.

If variation in range is substantial, it is a depression then sounds the unique tone. The microcontroller took measurement of ambient light using the LDR sensor. If light level is low suggesting night time, sound a unique tone.

Restart the process.

3. Results and Discussion

The parts of the system were put together and explored. Results were obtained from the analysis, experimental testing of the system as well as computer simulation of the system. The system comprises of the hardware and software (firmware) parts and looked at, from this point of view.

The system essentially measures distance using ultrasound technology. The distance between an object/person in front of the device being held by the visually impaired and by use of sound notifies the visually impaired if the object/person is close. (This helps in preventing head on collision).

The device is held by someone and approaches the front of a wall. As one gets closer, device starts to emit a unique musical tone of defined frequency. This is the point where the object/person in front is close enough and the visually impaired person must be warned so as to avoid head on collision with the wall/ approaching person. Also, the battery voltage was measured regularly with a voltmeter. The system was in use while the measurement was going on. When the battery voltage dropped to 6.8Volt, the device started to emit another unique musical tone of defined frequency. In other words, the testing of the system for object detection and measurement of the detected distance are shown in Figure 14 and 15.

Figure 14: Testing the system for object detection

A tape was used to measure the distances between the held device and the wall in other to know the distance at which the device starts to emit a unique musical note. This is compared with the distance programmed for the device to start emitting a unique tone which indicates that someone is approaching closely or an object is in front of the visually impaired person. This measurement helps in establishing device accuracy.

3.1 Measurements

Figure 15: Measurement of the detected distance

Time at which ultrasound energy is emitted = 2.000ms

Time at which ultrasound energy is received = 4.55ms

Time of flight = 4.55ms – 2.00ms = 2.55ms

D = distance/2 eqn 3.1

Distance = 340 * 2.55ms = 340 * 0.00255 = 0.867m

Actual distance between visually impaired person and object = 0.867/2 = 0.4335m

Hence this object is too close to the visually impaired person.

3.2 Discussion

Table 1 shows that when a person or an object is at most 350cm in front of the visually impaired person, the device emits a unique musical note. 350cm (3.5m) is about 6 steps away from the visually impaired. This gives enough room for him to walk normally and circumvent the person or object.

Also, the device's battery voltage was monitored. As the device was in use, a voltmeter was used to measure the battery voltage regularly. The table below shows the recorded voltage and the emitting of a unique musical note.

Let battery voltage = 9v
Scale ratio = 3
Maximum voltage at ADC input =
battery voltage / scale ratio ……. eqn 3.4
=> 9v/3 = 3v

This means that output voltage of voltage divider must be = maximum voltage at ADC input.

Hence use this information to get voltage divider resistor values

Let R1 = 1MΩ
R2 = ?

Hence, vo = R2/(R1 + R2) x vin ………….. eqn 3.5
where vin = battery voltage
Vo = maximum voltage at ADC input = 3v

Hence 3 = R2/ (1000000Ω + R2) x 9
R2 = 500000 Ω = 500KΩ

When battery voltage drops to 6v (this is the flat battery value)

From equation 3.4, maximum voltage at ADC input = battery voltage / scale ratio 6/3 = 2

From equation 3.5, Vo = R2/(R1 + R2) x Vin
Vo = 500000 / (1000000 + 500000) x 6
Vo = 2V

So, when the microcontroller ADC converts a voltage and gets 2V, the microcontroller will now beep to indicate low battery. This continues as the battery voltage drops until it drops to 6.8V at which time, the device begins to emit a unique musical note to warn the visually impaired that the battery on the device now needs to be changed.

The visually impaired person walking aid device equally has a feature that enables the device to be found if it falls off. Here, a button on the RF remote control device in Figure 4.3, which fits into the pocket of the visually impaired person, is pressed. If the walking aid is within 10m distance, it emits a unique musical tone. The visually impaired person follows the sound and picks up the device.

Therefore, Tables 1 and 2 show the recorded distance and the emitted unique musical note and also the battery on the device around 9V when the device does not emit any musical note respectively. Results recorded by [1] were compared with the result in Table 1, there is similarities which prove that the device is optimal in functionality, and also it covers a longer rang with respect to result recorded by [1]. This longer rang is also an advantage to the visually impaired as it will enable the VIPs to have information about the obstacles on time and makes a better deci-

Table 1: Measurement of distance for device in use

S/N	Measured Distance (cm)	Unique musical note	Musical note
1	500	No	No
2	400	No	No
3	350	Yes	Mee, ree, doo
4	300	Yes	Mee, ree, doo
5	250	Yes	Ree, mee, doo
6	200	Yes	Mee, doo, ree
7	150	Yes	Mee, doo, ree
8	100	Yes	Doo, ree, mee
9	50	Yes	Doo, ree, mee

Table 2: Measurement of battery voltage for device in use

S/N	Measured voltage (V)	Unique musical notes
1	9.2	No
2	8.9	No
3	8.1	No
4	7.7	No
5	7.5	No
6	7.2	No
7	6.8	Yes
8	6.5	Yes
9	6.0	Yes

Figure 16: The pocket size RF remote control

sion on time also.

The device is also capable of detecting when it is night time. This occurs when using the LDR sensor. Once the ambient light level drops off, which happens when it is night time. It equally emits a unique tone. Hence, the visually impaired immediately knows night has come.

4. Conclusion and Recommendations

An obstruction detection device for visually impaired people was designed using an ultrasound sensor, PIC16F877A microcontroller, RF module and other electronic components as shown in the previous chapters which were cased in a cow horn. The cow horn is very unique in terms of its flexibility and portability compared to other blind sticks which makes it obvious that the bearer is visually impaired. This device is very portable, robust, easy to use/operate, user friendly and affordable and also an ear piece is used so that only the bearer hears the sound (emitted notes) and also to reduce noise in the environment. From the test results the device was able to accomplish, is intended function which is for navigations by the visually impaired persons thereby reintegrating them into their environments and the society at large.

4.2 Recommendations

This device should be modified to include GPS and GSM module as to enable effective monitoring and tracking of the visually impaired. GPS identified the position and navigation of the device. GSM module assist in notifications via SMS sound when the visually impaired person faces danger.

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