Wearable Ultrasonic Device for Ranging to Prevent the Spread of the COVID-19 Virus

Chibuzo Joseph Nnonyelu[1, *], Ihechiluru Samuel Okoro[1], and Chidera Linda Anioke[2]
[1]*Department of Electrical Engineering, University of Nigeria, Nsukka, Enugu, Nigeria.*
[2]*Department of Electronic Engineering, University of Nigeria, Nsukka, Enugu, Nigeria.*
[*]Corresponding author: chibuzo.nnonyelu@unn.edu.ng

Abstract-The initial lack of vaccines and cure makes prevention the only approach to battling the deadly COVID-19. Consequently, the World Health Organization (WHO) issued preventive measures to curb the spread of the virus, which include among others, maintaining a minimum distance of one metre (3 feet) from people and avoiding crowded places. This paper, presents the design and construction of a wearable device that is capable of detecting and estimating the distance of people in front of the wearer and sounding a warning until the minimum safe distance is reached. Two variants of the design are proposed based on cost. The high-end variant uses the XL-MaxSonar MB1360 single-transceiver ultrasonic sensor and a voltage comparator, making it portable. The low-cost design, operating at just 95mW, uses the HC-SR04 ultrasonic sensor, timer circuit for triggering the ultrasonic sensor, a low-pass filter to extract the range as voltage level from the pulse-width-modulated output of the ultrasonic sensor, and voltage comparator to compare the voltage levels. A prototype of the low-cost variant was built, tested, and observed to meet 100% of design requirements.

Keywords: *ultrasonic sensors, COVID-19, wearable devices, circuit design.*

1. INTRODUCTION

In late December 2019, COVID-19, a novel corona virus epidemic broke out in Wuhan, China (Zhu, Wei, & Niu, 2020). In matter of weeks, 44,412 cases were confirmed in Wuhan and 74,280 confirmed for China totally, with 1497 and 2009 deaths recorded, respectively. On confirming other cases of COVID-19 outside China, the World Health Organization met on January 30, 2020 and declared the COVID-19 epidemic a public health emergency of international concern (Zhu et al., 2020). The virus is novel and a cure or vaccine is yet to be discovered; hence the international and local communities are working on ways to reduce or completely mitigate its spread. This led to restriction in travel both internationally and locally for some countries. In order to ensure the spread of the virus is curtailed, the World Health Organization issued measures of protecting oneself and others from it. These measures include among others, maintaining a minimum safe distance of 1 metre (3 feet) between oneself and others (WHO, 2020). We designed and constructed a low-cost wearable ultrasonic device, which will help remind the wearer to observe the minimum safe distance of 1 metre. This paper reports the design methodology and cost of this design.

There are two main technologies available for contactless ranging: infrared and ultrasonic. The choice of ultrasonic wave over the Infrared is due to the relatively short range obtainable with infrared sensors, its dependence on the colour of an object, and its susceptibility to light from the sun. This would require extra sensors and circuitry to eliminate the effect of sunlight on the performance of the infrared sensors (O'connor, Davis Jr., Vernaz, & Hawley, 2004), and this translates to increased cost.

There are different circuit designs around ultrasonic sensors for distance measurements in the open literature. The HC-SR04 ultrasonic sensor was used with Arduino microcontroller for distance measurement and display using 16x2 LCD display (Saddam, 2015). The SFR08 ultrasonic sensor was used for distance measurement to ascertain the accuracy of the device in long-range measurement. This circuit was connected directly to the PC for real-time processing (Koval, Vaňuš, & Bilík, 2016). Wang designed an ultrasonic ranging device and transmitting the measurement wirelessly (Wang, Liu, Chen, & Xue, 2013). A common feature of the designs discussed here is the use of software, hence a processor or microcontroller to interpret and apply the measured distance. The design proposed in our work is free of microcontrollers hence, is energy efficient and cost effective.

Section 2 discussed the system design and description. The implementation and testing of the system are discussed in Section 3. Finally, Section 4 concludes the paper.

2. SYSTEM DESIGN AND DESCRIPTION

In this section, the design of the system is presented and discussed. The block diagram of the design is shown in Error: Reference source not found and consists of the BL-5C Li-ion battery, a timer unit, the HR-S04 Ultrasonic sensor, a low pass filter, and a comparator. Each block is discussed subsequently with corresponding circuit diagrams where applicable.

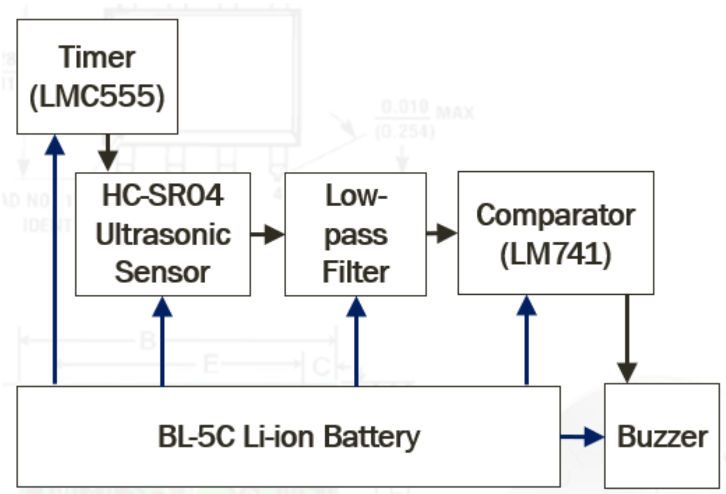

Figure 1: Block diagram of the design.

A. The Ultrasonic Sensor

This project design comes in two variants: low-cost and high-end variants. These variants were motivated by the cost of the ultrasonic sensors used. The high-end variant employed the single-transducer ultrasonic sensor XL-MaxSonar MB1360 from MatBotix (MatBotix, 2020) (please see Figure 2a).

(a) XL-MaxSonar MB1360.

(b) HC-SR04.

Figure 2: The ultrasonic sensors for (a) high-end variant and (b) low-cost variant.

The low-cost variant of the proposed device uses the cheap and readily available ultrasonic sensor, the HC-SR04 to achieve the design objectives (see Figure 2b). This ultrasonic sensor, unlike the XL-MaxSonar MB1360, requires a low duty cycle pulse (with on time $10\mu s$) to trigger the sensor into emitting a 40-kHz sound and listens for its reflection. The length of time taken to travel to and from the object in front of the sensor is embedded in a pulse width. In other words, the distance information is presented as a pulse-width modulated signal. The closer the object, the lower the pulse width and vice versa.

B. The Timer Circuit

The pulse needed to trigger the HC-SR04 is generated using the LMC555 timer IC configured in astable mode. Normally, the 555-timer cannot produce duty cycle less than 50%. However, when the output is inverted, duty cycles as low as 10% can be achieved (Keith, 2016). The resistors and capacitor values needed to achieve this are calculated using

$$t_{OFF}=0.693R6+R4\times C4 \qquad (1)$$

where R4,R6 and C4 are as shown in the full circuit diagram shown in Figure 3. Therefore, $t_{OFF} = 0.693(1 + 10)\times 10^3 \times 0.01\times 10^{-6} = 76.23\mu s$. The ON time of the timer is calculated as

$$t_{ON}=0.693\, R4\times C4 \qquad (2)$$

which gives $t_{ON}=0.693\times 10\times 10^3\times 0.01\times 10^{-6} = 69.3\,\mu s$ which is greater than the minimum 10µs ON time specified in the datasheet. This gives a duty circle of $100\times t_{ON}/(t_{ON}+t_{OFF})=47\%$. This value is below the 50% mark and is considered low duty cycle as specified in the device datasheet.

Note that C4 is tied to VCC rather than common and that R5 and R6 charge it in the negative direction. By connecting C4 to VCC, the relatively high discharge current does not run through the power source. The reset transistor (T2) discharges the capacitor in the positive direction. R5 and R6 are determined using (1) and (2). R4 is a pull-up resistor for the open collector output (pin 7) so it can drive the emitter follower (or source follower) reset transistor.

The high-end variant uses the MB1360 ultrasonic sensor and does not require an external timer circuit to be triggered. This elimination of the timer circuit further improves on the portability and energy efficiency.

C. The Low-pass Filter

The range information from the ultrasonic sensor is embedded in the width of a pulse-width modulated train. This distance information in the pulse width is extracted by means of a simple RC low-pass filter. This low-pass filter outputs the pulse width as a DC level. This implies that the closer the object, the lesser the DC voltage level, and vice versa. The output of the low-pass filter is fed into the inverting input of the comparator (LM741 op-amp).

The high-end variant does not require the low-pass filter as the MB1360 outputs the distance measurement as voltage level. This elimination of the low-pass filter stage further improves the portability and energy efficiency.

D. The Comparator

A variable resistor is used to set the threshold voltage at the non-inverting input of the op-amp using voltage divider method. Once the object enters the one-metre range, the width of the echo pulse of the ultrasonic sensor reduces, which means a decrease in the DC level of the output of the low-pass filter, then the comparator outputs its positive supply voltage which is fed into a current buffer. This current buffer provides enough current to drive the buzzer.

E. The power supply

Two BL-5C Li-ion batteries were used in series as power source for the low-cost variant of the device. A voltage regulator IC, LM 7805, was used to regulate the supply voltage at 5V. This battery is rechargeable and easily obtainable from local stores. This makes it possible to recharge the battery using available mobile phone chargers. For the high-end variant, the CR2025 or any rechargeable coin cell such as ICR 2032 is used.

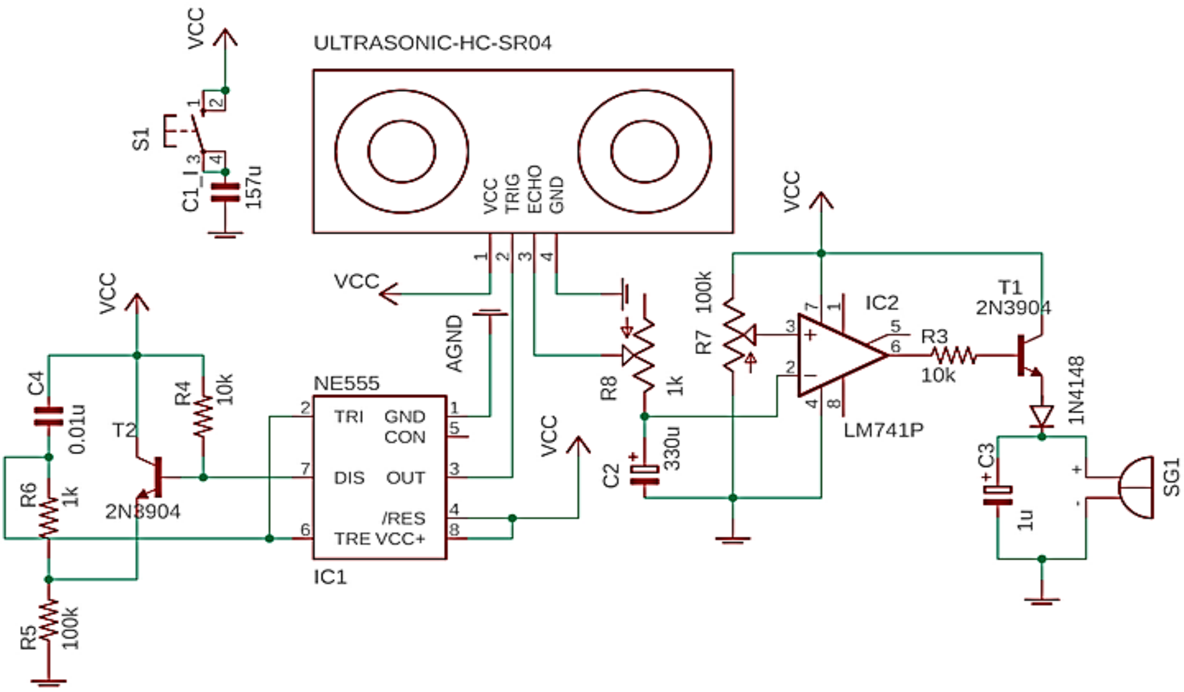

Figure 3: The complete circuit diagram.

3. IMPLEMENTATION AND TESTING

A prototype of the final design was temporarily constructed and tested on a bread board. After the circuit is confirmed to work, the final circuit was transferred to a permanent board (the Veroboard). Different test scenarios were performed in order to ascertain the efficacy of the product.

The operating current of the device was measured in idle mode and when operating in full load mode (buzzer is sounding).

Table 1: Operating modes with corresponding current and power.

Operating mode	**Current (mA)**	**Power (mW)**
Idle mode	3	15
Full load mode	19	95

With a full charge capacity of 1150mAh, the BL-5C battery can power the device for a minimum of two and half days. And it takes nearly an hour to fully charge. For the high-end variant, the CR2025 or IFR2032 coin cell is used which improves its portability.

4. Conclusion

A wearable device for warning the user to maintain the recommended one-metre safe distance has been designed. The low-cost variant was built and tested. The device avoided the use of microcontroller mainly to reduce the overall size, improve the ergonomics and energy consumption. This reduced the full load power to 95mW, enabling the battery to last for up to two and half days on full charge. The produced low-cost variant used the easily available HC-SR04 ultrasonic and cost a total of just NGN3000.

Acknowledgement

This project was sponsored by Engr. Prof. Emenike C. Ejiogu Covid-19 Research Fund Initiative for Young Academics of the Faculty of Engineering, University of Nigeria, Nsukka.

References

Keith, J. (2016). Inverted 555 Timer Circuit. Retrieved December 4, 2020, from https://www.electroschematics.com/inverted-555-timer-circuit/

Koval, L., Vaňuš, J., & Bilík, P. (2016). Distance Measuring by Ultrasonic Sensor. *IFAC-PapersOnLine*, *49*(25), 153–158. https://doi.org/https://doi.org/10.1016/j.ifacol.2016.12.026

MatBotix. (2020). MB1360 XL-MaxSonar-AEL0. Retrieved December 4, 2020, from https://www.maxbotix.com/ultrasonic_sensors/mb1360.htm

O'connor, C. J., Davis Jr., J. D., Vernaz, T. R., & Hawley, S. A. (2004). Infrared obstacle detection in the presence of sunlight. Retrieved from http://www.freepatentsonline.com/6812466.html

Saddam. (2015). Distance Measurement using Ultrasonic Sensor and Arduino. Retrieved December 4, 2020, from https://circuitdigest.com/microcontroller-projects/arduino-ultrasonic-sensor-based-distance-measurement

Wang, S., Liu, Q., Chen, S., & Xue, Y. (2013). Design and Application of Distance Measure Ultrasonic Sensor. In D. Jin & S. Lin (Eds.), *Advances in Mechanical and Electronic Engineering* (pp. 109–114). Berlin, Heidelberg: Springer Berlin Heidelberg.

WHO. (2020). Coronavirus disease (COVID-19) advice for the public. Retrieved June 1, 2020, from https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

Zhu, H., Wei, L., & Niu, P. (2020). The novel coronavirus outbreak in Wuhan, China. *Global Health Research and Policy*, *5*(1), 6. https://doi.org/10.1186/s41256-020-00135-6