Developing an Assistive Device for the Visually Impaired Using Ultrasonic Sensors for Distance and Solidity Determination

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Abstract: In the Philippines, there are approximately 340,000 visually impaired Filipinos. Today, the white cane is the most commonly used to aid the blind in navigating their surroundings; however, it allows a range of visualization limited by the length of the stick, while surfaces at closer range are better served by and sensed by hand. This paper presents the development of an assistive device that utilizes ultrasonic sensors to provide both distance and a measure of density of the surface in the immediate surrounding environment of the user. By providing this information pair, the user may better understand their immediate surrounding environment, navigating it safely and quickly. A prototype was designed and built for the participants to use in navigating an indoor-outdoor course. Trials of the prototype showed that it had comparable performance with a walking stick with a slightly quicker course navigation time.

Key Words: ultrasonic sensor; electronic travel aid; obstacle avoidance; obstacle detection; assistive device

1. INTRODUCTION

Visual impairment affects many lives globally and in the Philippines, there are about 332,150 bilaterally blind people (DOH, 2017). However, despite the growing number of visual impairment in the country, eye care is still the least priority in public health (Robles, 2018).

The visually impaired face a lot of challenges in their daily lives especially in terms of navigation due to the unpredictability of their environment (Riazi et. al., 2016; Slade et al., 2017). In order to navigate around, several options were made to assist the visually impaired such as the walking stick, the most common assistive device for the blind (Illinois Library, n.d.). However, its most important limitation is that it only allows a limited range of visualization that is within the reach of the arm or the stick. Besides this, it is difficult to use at close range with the object.

To solve these limitations, different blind assistive devices have been proposed. Assistive devices today make use of a variety of sensors, specifically ultrasonic sensors (Elmannai & Elleithy, 2017). These sensors appear to be suitable in the context of this study since they can detect almost all types of materials, are low cost, and are unaffected by small temperature changes (Gillespie, 2019).

This study was pursued to design an ultrasonic sensor assistive device that may increase the degree of independence of visually impaired Filipinos by providing material density along with proximity information. To achieve this, the research aims to identify the characteristics and limitations of the current ultrasonic assistive devices; develop a prototype of an ultrasonic sensor assistive device; and characterize its effectiveness with metrics.

The findings of this study will benefit the visually impaired community, as this study aims to develop a device that may increase their degree of independence so they could navigate around a flat and a rocky terrain without worrying about their safety. Also, communities in which they belong to would be more confident in the safety of the visually impaired and they would no longer need to avoid their path. Finally, this study will benefit future researchers as this may provide them with recent data on ultrasonic assistive devices and visual impairment in the country. Researchers from other disciplines such as the behavioral sciences will also benefit from the information on how the visually impaired create mental pictures of their environment.

2. THEORY

2.1 Amplitude and Time-of-Flight

Ultrasonic sensors use frequencies in the form of ultrasonic sound waves to determine the distance between itself and the closest object in its path (Morgan, 2014; Abdullah, 2015). The sensor sends out a sound wave at a specific frequency and will wait for that particular sound wave to reflect on an object and come back. The distance of an obstacle is calculated using the time-of-flight method:

$$L = \frac{1}{2} ct \qquad \text{(Eq 1.)}$$

where:
L = distance between sensor and the object (m)
c = ultrasonic speed in the medium measured (m/s)
t = time of flight of ultrasonic pulse (s)

The maximum measurable distance is dependent on the detectable limit of the returned signal bouncing off an object, i.e. its echo. The reflectivity of an object is dependent on the ratio of its material's acoustic impedance versus the acoustic impedance of the transmission medium, which in this case, is air.

2.2 Acoustic Impedance

Ultrasonic acoustic impedance is the ratio of acoustic pressure to the volume flow (University of New South Wales, n.d.). The formula used for getting the acoustic impedance and specific acoustic impedance is as follows:

$$z = p/u \qquad \text{(Eq. 2)}$$

where:
z = specific acoustic impedance
p = acoustic pressure
u = acoustic flow velocity

An impedance mismatch is defined as the difference of acoustic impedances of the materials at the boundaries where ultrasonic waves reflect (NDT Resource Center, n.d.). The unit of measurement is Rayleigh (Rayl).

The strength of reflection at a given distance can then be a proxy to the hardness of the material's surface. Given the knowledge of how far a surface is, using traditional time-of-flight measurements, and being able to measure the strength of the echo, an estimate of the material's density can be determined.

The equation below can be used in finding the incident wave intensity fraction when both acoustic impedances from the sides are known:

$$R = (Z_2 - Z_1 / Z_2 + Z_1) \qquad \text{(Eq. 3)}$$

Once all values are plugged in and a result is obtained, this is called the "reflection coefficient". It may be multiplied to 100 to get the amount of reflected energy as a percentage of the initial energy.

3. METHODOLOGY

3.1 Software Design and Development

During the initial step of characterizing an HC-SR04 ultrasonic sensor, a distance detection program was coded and uploaded to a Gizduino+ w/ ATmega644 board. A program for determining the solidity of objects was written as well.

3.2 Hardware Design and Development

Hardware and software design and development were done simultaneously. After uploading the program to the Gizduino board, the HC-SR04 sensor was connected to a digital oscilloscope. At three trials, three different materials were placed in front of the sensor at four arbitrary distances, starting at 0.25m. The average amplitude for a distance was calculated as well as its variance and this was repeated for all materials.

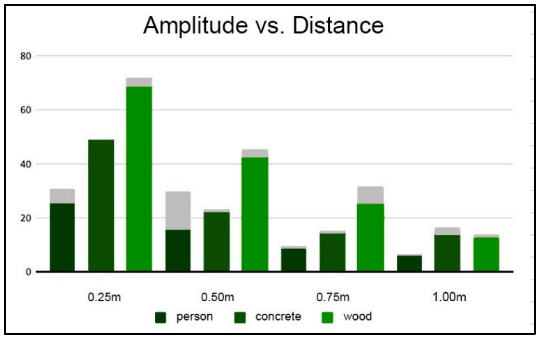

Fig. 1. A bar graph of the average amplitudes of the materials and their variances versus distance.

Figure 1 shows a stacked column of the data gathered from characterizing the sensor. The green columns represent the average amplitude that the materials produced at different distances, whilst the grey columns signify the variance of the amplitudes. Based on the graph, the person has the smallest amplitude among the three (Figure 1). This signifies that the person is the least "solid" as it is the least "intact" and has the most "irregular shape", and these are some factors that affect sound waves. On the other hand, concrete and wood are relatively uniform in shape and composition; thus, the return of the sound wave is bigger in terms of its amplitude.

The variance was calculated to show whether the sensor was consistent with its measurements or not. Based on Figure 1, there is an insignificant difference in the variance except for person at 0.50 m. This fluctuation might be caused by difficulty in capturing waves due to possible faulty wire connections and the sensor detecting the material from another angle.

For sensor interfacing, a signal conditioning chain composed of amplification, peak detection and envelope generation was implemented. This circuit amplifies ~40KHz waves from the echo as small as 10mV into a range and signal period more suitable for the ADC of the Arduino. A higher voltage means that the object provided a stronger reflection. The feedback system in the prototype uses two piezo-buzzers for notifying the distance and solidity measurements.

The circuit was interfaced to an HC-SR04 ultrasonic module controlled by an Arduino. It was connected to the oscilloscope to see the waveform and the peak-to-peak voltage (Vpp). Table 1 lists the resulting output signal Vpp and the corresponding gain. Results show that the output signal was amplified to approximately 40x the input signal.

Table 1. Peak detection at 40kHz

Peak Detection at 40kHz		
Input Signal Vpp (mV)	Output Signal Vpp (mV)	Gain
10	420	42
20	880	44
30	1400	46.67
40	1860	46.5
50	2380	47.6
60	2880	48
70	3400	49.86

The prototype was completed by building a small case for the electronics and was attached to the end of a one-meter stick.

3.3 Prototype Testing and Data Collection

Data collection procedures were adapted from Lee et al (2014)'s study. The test was run with

16 participants who were divided into two groups: Group 1 was composed of the walking stick users whilst Group 2 were the prototype users. The participants were instructed to navigate the course using the assistive device they were provided with. They were supervised by three researchers who recorded the collision frequency and course completion time, and video recorded each participant.

4. RESULTS AND DISCUSSION

4.1 Indoor-Outdoor Testing

The two groups were oriented prior to the experiment proper by allowing them to use the device with and without blindfold in an indoor-outdoor environment.

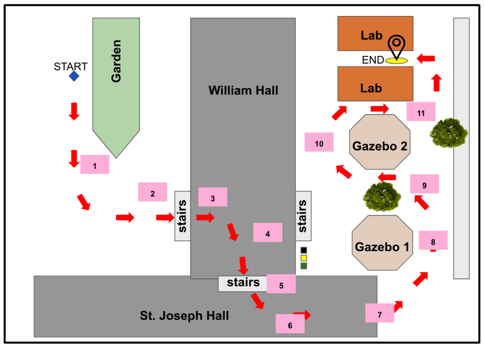

Fig. 2. Indoor-outdoor course for the trial.

Figure 2 shows the course the participants underwent. The outdoor portion had varying elevations and cement pavement with rough finishes. Small plants and lampposts were some obstacles present. As for the indoor portion, participants had to walk through stairs and hallways. They were also required to follow checkpoints to remove the randomness in the routes that they were taking as they would all go the same path. The participants were video recorded and a post interview was conducted.

4.2 Collision Frequency

The experiment trial shows that the average collision frequency of walking stick users is 1.125 while the prototype users have 0.75 collisions for the course. Although there is only a small difference between the two groups, data shows that users of the prototype had fewer collisions with objects. This could mean that the feedback system was successful in alerting the user of the obstacles. Conversely, the users of the traditional walking stick had no means of any feedback system that would notify them of the obstacle in front of them only until the obstacle is within the reach of the walking stick.

4.3 Course Completion

Checkpoints were present in the route to help the user know whether he or she is on the right path. Based on the results of the experiment, prototype users had a faster course completion than those who used the traditional walking stick. Walking stick users had a longer course completion time (429.965 s) than prototype users (393.7225 s) by roughly 36 seconds.

Figure 3 below shows a bar graph of the average time each participant had for each checkpoint.

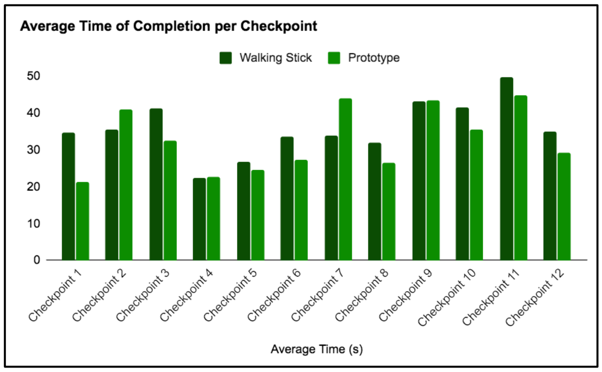

Fig. 3. Average time of each participant for each checkpoint.

Since both groups were taking the same route, the difference in time may be attributed to the ability of the prototype to alert the user of the proximity information and its solidity while it was still at an ideal distance, unlike in a walking stick where it could only sense the solidity of an object by tapping on it as the object was within its reach.

5. CONCLUSIONS

The study was conducted to develop an ultrasonic assistive device that would increase the degree of independence of the visually impaired.

Results from sensor characterization show that there is a directly proportional relationship between the hardness of the material and the wave amplitude. As for sensor interfacing, a peak detection circuit was designed for wave amplification and rectification.

Participants of the study underwent an indoor-outdoor course. Results show that those who used the prototype had a faster course completion time and lower collision frequency than those who used a traditional walking stick. Hence, it can be concluded that the prototype was able to provide sufficient information to alert the users of the obstacles and successfully reroute them.

6. RECOMMENDATIONS

A greater number of participants is recommended for future performance testing to get a more statistically accurate data since a small sample size could result to data that is skewed to one side.

Testing the device more extensively in various indoor and outdoor environments is recommended as this may help determine the limitations of the prototype and further improve its interface.

Based on the post-interview, participants deemed the prototype uncomfortable to use. Hence, the ergonomics of the assistive device can be improved in future research.

Using a different sensor is suggested to modify the device. Sensors that have a wider and longer range of detection is recommended to be used.

7. ACKNOWLEDGMENTS

The researchers would like to thank AdRIC's Center for Automation Research for allowing us to utilize the facilities and test equipment for the development of our prototype.

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