Hearing Test Device

Problem Definition:

According to the World Health Organization, over 360 million people worldwide have disabling hearing loss, costing 750 billion dollars internationally every year [1]. Hearing loss can make it difficult to understand conversational speech, leading to miscommunications in one's personal and social activities and in the workplace. The earlier hearing loss is detected, the sooner a person can receive the appropriate assistance they need, such as hearing aids, cochlear implants, closed captioning, sign language, etc.

A simple and feasible technological approach to detecting hearing loss is emitting particular sounds and observing if the user is able to hear them. Hearing loss can be tested by measuring how loud a person could hear in decibels (dB), but even brief exposure to high-volume sounds can cause permanent damage to hair cells along the basilar membrane [2]. A safer way to test hearing loss is by measuring sound created by pressure waves that oscillate through matter at a particular rate, or frequency, in hertz (Hz). The higher the frequency of the sound, the higher the pitch.

The purpose of the device we are creating is to test a user's hearing by taking in input for the user's age, generating frequencies within the human hearing range of 20 to 20,000 hertz, and comparing the highest and lowest frequencies the user could hear with the average data for their age group. This can indicate whether the user might have more difficulty hearing higher or lower pitched sounds compared to most people their age.

Hearing loss in higher frequencies caused by aging is a common phenomena called presbycusis [3,4]. Reverse-slope hearing loss can cause the opposite to happen, where people's low-frequency hearing deteriorates with age [4]. Noise-induced hearing loss also makes it harder to hear lower frequencies. The device will utilize headphones to test for these different types of hearing loss in both ears and report if the user may have hearing loss as well as potential causes.

Although tests for hearing loss are widespread, most of them utilize either expensive or cumbersome equipment. For example, the brainstem auditory evoked responses test measures the hearing limitations in the brainstem using precisely placed electrodes. Such a test requires extensive audiology

References

[1] http://www.who.int/mediacentre/factsheets/fs300/en/

[2] https://www.nidcd.nih.gov/health/noise-induced-hearing-loss
[3] https://www.scientificamerican.com/article/bring-science-home-high-frequency-hearing/
[4] http://hearinglosshelp.com/blog/the-bizarre-world-of-extreme-reverse-slope-hearing-loss/

Statement of Impact in Developing World:

Hearing loss is a prevalent issue in developing countries with little to no access to healthcare. One in three people over the age of 65 have hearing loss, and it is most common in developing countries like South Asia and sub-Saharan Africa [1]. A fast and simple device to determine the type and severity of hearing loss would allow countries to better identify the population affected by hearing loss and be better equipped to get them the early aid.

Currently, basic hearing tests are administered through the use of expensive and bulky tuning forks that resonate at static frequencies. Successfully creating a hearing test device that can diagnose the limitations of a person's cochlea without the need for additional equipment can be used in low-resource settings.

The total cost will ideally be less than $100 to provide a low-cost and easily reproducible alternative to more expensive hearing tests. It will also be relatively small (smaller than a cubic foot) for ease of portability. The device will be operated using rechargeable batteries so that it may be used in any country without the concern of unique electrical outlets. Battery life ideally will ideally allow the device to run several hours, during which hundreds of hearing tests can be conducted, before requiring recharging to maximize efficiency.

If successful, further modifications may include adding another headset with a component that aids hearing so users can test if the hearing aid actually helps them. One potential method of aiding hearing is to shift frequencies that are outside the user's hearing range higher or lower so that they are able to hear it. Another option is to amplify the magnitude of the signal by applying a gain to the frequencies that are not heard well, while filtering out the rest of the frequencies that are detected by the user. This allows the hearing aid to be customizable to the user's hearing abilities specifically.

References
[1] http://www.who.int/mediacentre/factsheets/fs300/en/

Required Performance Specifications:

We divided the performance goals for our prototype into four categories:

- **Functionality**
  - **Age input**: The device is able to take in user input for age.
  - **Frequency tests**: The device is able to conduct a low to high frequency test (20-20kHz) and a high to low frequency test starting at 3000 Hz.
  - **Age to average comparison**: The device informs the user of the average frequency heard based on their selected age group and compares this average to the frequencies they were able to hear to in order to determine whether or not they may have hearing loss.

The following data is used as the baseline for comparison:

Age (years)	Frequency (Hz)
Under 20 (0-19)	19,000
20-24	17,500
25-29	16,000
30-39	15,000
40+	12,000

Table 1. Average highest frequencies heard by different age groups[5,6].

- **Cost efficiency**
  - Total cost under $100

- **Portability**
  - **Weight**: under 1 lb.
  - **Size**: under one cubic foot
  - **Appearance**: Device enclosed in a 3D printed casing for ease in handling and transport. Knobs to control volume, age selection, and LCD brightness

- **Practicality**
  - Device either rechargeable or battery-operated
  - Device fully independent (no additional technology required)

[5] https://www.echalk.co.uk/Science/biology/hearing/HowOldIsYourHearing/resource.html
[6] http://www.iflscience.com/health-and-medicine/test-how-old-are-your-ears/

Implementation of Prototype:

The entire device is coded and operated using Arduino programming. In the development stages of the prototype, all components were connected to an Arduino Uno (figure 1), which we were successfully able to replace with an ATMega328P integrated circuit (IC) chip, thus significantly reducing the size of the device. The wiring of all components can be seen in figures (2) and (3) of the attached appendix.

At the beginning of the hearing test, the LCD displays instructions for inputting age to the serial monitor on the computer screen. After the user types their age, the headphones begins generating frequencies starting at 20 Hz and incrementing by 20 Hz every 20 milliseconds up to 20,000 Hz. The user keeps listening until they can no longer clearly hear the sound, at which point they press the button. When the button is pressed, the speaker stops playing sound and the LCD reports the last frequency the user could hear and compares their result to the average highest frequency heard for their age range. A second hearing test begins, but starts at 3000 Hz and decreases 20 Hz every 20 milliseconds until the user again is unable to hear sound. If the user is unable to hear above 2000 Hz, potential low frequency hearing loss is reported.

The RGB LED changes color for different frequency ranges. One potentiometer controls the LCD's brightness, another controls the volume of the sound through the headphones, and the third potentiometer is used to select the user's age group.

In order to successfully transfer our design to a printed circuit board, we used AutoDesk Eagle to design the circuit we made. A schematic of the design is shown in figure (3) of the appendix.

Proof of Performance:

Below is an assessment of our prototype against the criteria we outlined in the required performance specifications:

- **Functionality**
  - **Age input**: The device is able to take in user input for age.
  - **Frequency tests**: The device is able to conduct a low to high frequency test (20-20kHz) and a high to low frequency test starting at 3000 Hz. However, the signal is noisy at high frequencies (upwards of 13kHz).
  - **Age to average comparison**: The device informs the user of the average frequency heard based on their selected age group
- **Cost Efficiency**

Below is the list of parts we ordered for the project. The total comes down to about $62, which is less than our target cost of $100.

Part Name	Unit Cost	Quantity	Total
Amplifier	$8.55	1	$8.55
LCD	$15.95	1	$15.95
Potentiometer	$0.95	2	$1.9
330 Ohm Resistor	$0.95	1	$0.95
10K Ohm Resistor	$0.95	1	$0.95
Barrel jack	$1.25	1	$1.25
Battery jack connector	$3.95	1	$3.95
Button	$0.35	2	$0.7
RGB LED	$1.95	1	$1.95
Audio connector	$4.91	1	$4.91
Headphones	$7.89	1	$7.89
ATmega328 IC	$5.50	1	$5.5
Crystal 16 MHz	$0.95	1	$0.95
AA batteries	$5.94	1	$5.94
	Grand Total		**$61.34**

- **Portability**
  - **Weight**: The weight is under 1 lb.

    - **Size**: The size is under 1 cubic foot.
    - **Case**: The device is currently not enclosed in a casing.
- **Practicality**
    - **Power source**: The device is currently powered by connecting the Arduino setup to a battery pack, so it is fully independent.

Although we successfully recreated the design on a printed circuit board, the PCB was unable to run the code, so our design is still on a breadboard. We designed and 3D printed a case for the PCB, so if in the future the PCB is able to work, the device is complete. Figure 5 shows the PCB inside the plastic case with the components soldered on.

Below is a link to a YouTube video demonstrating the working circuit:
https://youtu.be/PH3FxQAvPCU

Business Plan for Manufacturing and Distribution of Technology:

- **Customer**
    - This product could either be distributed via a nonprofit organization or charity to those in need or be sold on the market in developing countries. It would most likely be sold to hospitals in need of testing hearing quickly and efficiently without the need for expensive equipment, but has the versatility to be sold for commercial use as well.

- **Funding**
    - Hospitals and organizations interested in using the product could invest in the product. Due to the relatively low cost of the product, the technology is sustainable with sales; it is the cost of manufacturing that requires careful consideration. Revenues would depend on the amount of devices needed to break even with the manufacturing costs; any additional devices sold would result in a profit.

- **Manufacturing**
    - As aforementioned, the total cost of the device is $61.34. In order to reproduce this device, a manufacturing plant would require machines with soldering capabilities to solder all the individual components onto the PCB and 3D printers to print the PCB as well as the plastic casing.
    - Due to these requirements, this device cannot be manufactured in a low resource setting. The device would be manufactured in a facility with the necessary resources and then shipped to developing nations.

- **Distribution**
    - The device would most likely be distributed by a hospital to patients in need or by a nonprofit organization, but the device can also be sold commercially on the market. A partnership between nonprofit organizations and hospitals would be ideal for maximizing the amount of people that can be assisted.

- **Regulation**
    - I would seek a patent for the device. The technology would most likely require FDA approval before it can be manufactured and distributed to foreign countries, especially hospitals where the safety of the patients is at stake. However, the device will be sold with the disclaimer that it is not intended to provide a sole diagnosis for hearing or aid hearing.

Appendix:

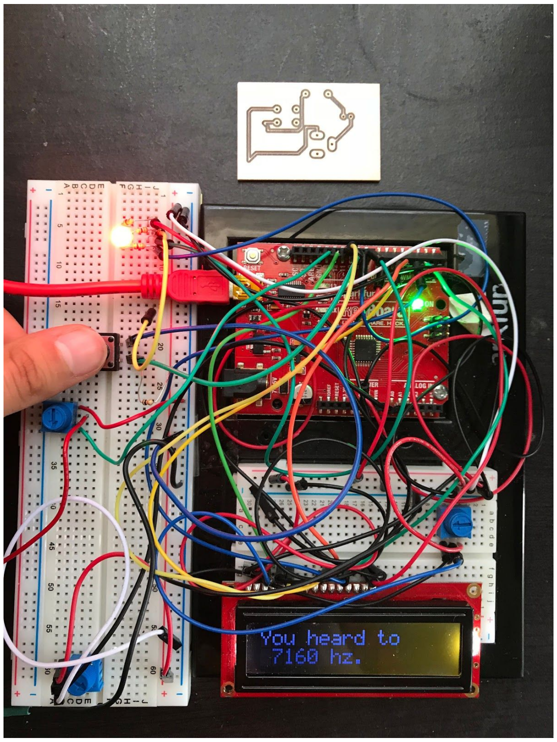

Figure 1. Wiring setup

Printed circuit board

Arduino Uno

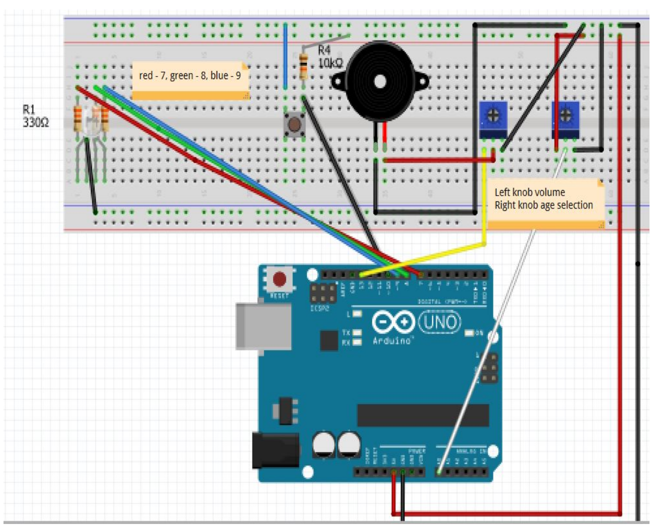

Figure 2. Fritzing diagram of Arduino setup.

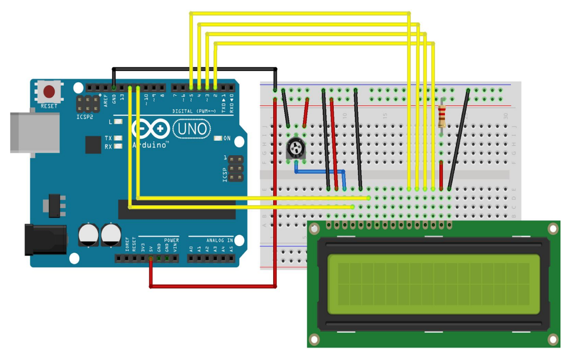

Figure 3. LCD setup.

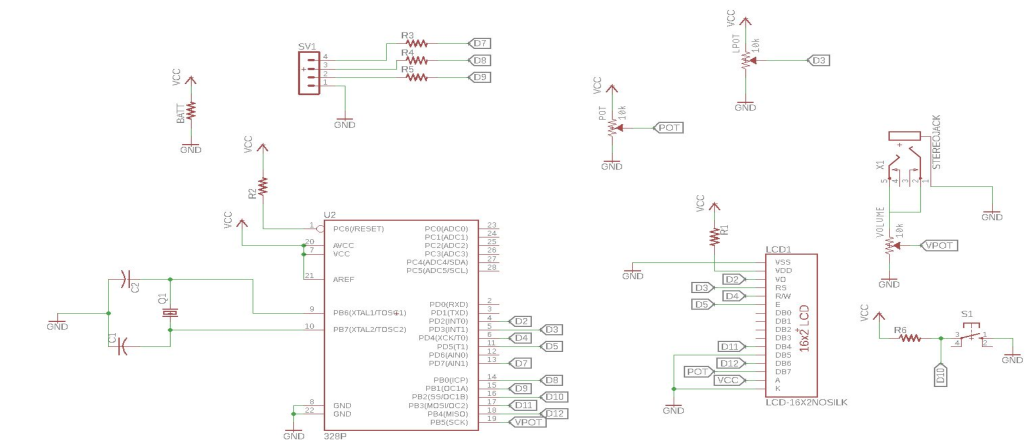

Figure 4. Schematic of design in Eagle.

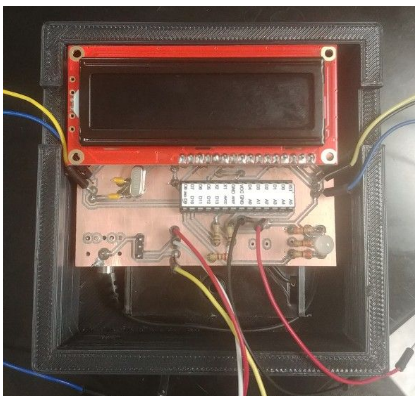

Figure 5. PCB inside plastic case.