Hearing Phone

Turn your phone into a go-anywhere backup hearing aid, complete with a remote microphone

Problem Statement

According to the NIH, 2 to 3 of each 1,000 children are born with hearing loss. Furthermore, while almost 29 million American adults could benefit from hearing aids, less than one-third have ever used them. [6] While NIH does not go into why so many people with hearing loss go without hearing aids, a possible stigma about having to wear hearing aids may be one reason, but cost also likely plays a large role. For example, my six-year-old son, Luke, wears hearing aids, and his aids list for about $5,000. A Facebook group for parents of children with hearing loss I'm a part of parents struggling to affording such a huge expense—one that gets repeated as hearing aids need replacement.

While hearing aids have greatly enhanced Luke's ability to learn and understand, one big drawback is that they are not water-resistant. The lack of water resistance forces us to remove Luke's aids when going to the pool, a waterpark—even when it is raining, or he is going to sweat a lot.

The cost of replacement hearing aids is one reason we are so careful around water, but the cost of accessories further limits the usefulness of Luke's aids. Luke's school uses what is known as an "FM system", which allows his teachers to use a microphone to talk directly into Luke's hearing aids. (For a more detailed description, see [7].) While my wife and I have considered getting a system like this for when we go to busy/noisy places, the cost is prohibitive.

By contrast, consider the recent advances in smartphones. Smartphones cost far less than hearing aids, and most of us now carry one (and may well have a 2nd phone lying around). The microphones in smartphones have improved greatly as phone makers focus on video recording and background noise cancellation. More importantly here, many phones and headphones are now water-resistant. In addition, central to all smartphones are connections—to the Internet, to headphones, and even to other phones.

Many apps will act as quasi-hearing aids, including the ability to adjust the frequency response of the audio output. I could not find one, however, that will also allow a parent to talk into the phone from across the room (like a school's FM system). With a remote audio feature, a phone could not only fill in when hearing aids are not an option, but could also allow a parent or caregiver to keep in touch when not in earshot.

Methods/Approach/Solutions Considered

My familiarity with Java (the most prevalent programming language for Android apps) and having extra Android devices around the house made Android the best platform for a prototype.

Android gives you several modes for audio recording. For emulating hearing aids, the "camcorder" mode works best, as it will pick up sound from all around the phone (rather than just what is right next to the microphone). This mode will also continue to use the phone's mics even when a headset is plugged in. For a remote microphone, the "mic" mode will pick up only what is right by the microphone.

To allow someone to speak into headphones directly, my initial idea was to use a single phone, recording both the phone's microphones and a Bluetooth headset. I discovered, however, that Android will not record from two sources at once (even across two different apps). I then decided to look at connecting two phones together over WiFi direct.

WiFi direct, as the name implies, allows two devices to connect directly to each other, which both reduces lag (the time it takes for sound to travel between the phones, in this case) and allows phones to connect even when not connected to a WiFi network. In Hearing Phone's setup, the audio sent over WiFi direct is played in addition to the audio the phone's microphones pick up.

Another question Hearing Phone answers is how people with hearing loss can customize the sound they get through the app (i.e., to boost certain frequencies over others). My initial approach was to use audiogram results to set up an equalizer, but this solution does not account for the wide variation in headphone quality—in particular, bass response can vary a great deal between models. The approach I chose instead was to let the user tune the output by listening to sounds at various frequencies and adjusting the output as needed.

Another design concern is audio latency. In a study of lipreaders, the Journal of the Acoustical Society of America found that an audio delay of more than 40 milliseconds (ms) could cause people with normal hearing to have trouble matching sounds to moving lips.[4] With a user's own voice, even a delay of 3-5 ms is often noticeable.[5] In another study concerning haptic actions vs. sound reproduction, most users noticed a gap when the delay between touching an object and hearing an audio response was at least 24 milliseconds, although one user noticed a gap as low as 8-10 ms.[2] As recently as 2012, Android had real latency problems[3], but recent improvements—including a low-latency playback mode in Android 8.0 Oreo—have improved matters. (In my testing with Android 8.0's low-latency mode, I could hear an audio gap between speaking and hearing my voice repeated back, but not when focusing on my lips in a mirror. (It should be noted that iPhone, according to low-latency audio library maker SuperPowered, does not have these latency issues[1].) For the prototype I stuck with Android's built-in audio recording and playback, with a library like SuperPowered as a possible way to further reduce latency.

Description of Final Approach and Design

Figure 1: Main app screen

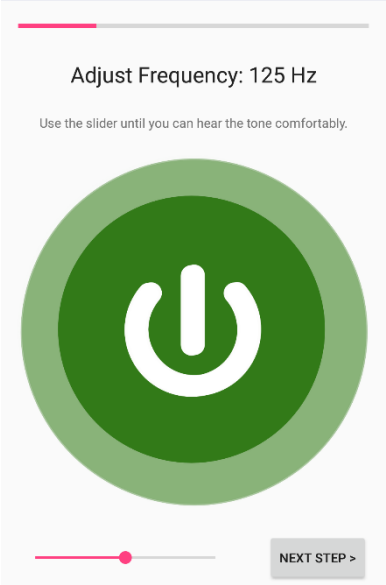

Figure 2: Creating a preset

Figure 3: Sending audio to another device

The prototype is an Android app that allows people with hearing loss to listen to what the phone hears, as well as allow a parent/caregiver/teacher to talk to them from the same app running on a separate device.

The main screen, shown in Figure 1, makes it obvious how to start listening to the phone's microphones. (My son even referred called the prototype the "blue and green app".) It also provides a shortcut for creating a preset for headphones.

Also shown in Figure 1 are the controls for using a remote microphone. The switch labeled "Allow Remote Mic:" is a security measure that prevents the app from looking for remote audio until the user is ready. The icon at the bottom-right takes you to the screen where you can make a connection to a phone that's listening for connections (Figure 3).

Figure 2 demonstrates one piece of the preset customization wizard. After setting a base volume, the app guides the user to adjust different frequencies to best suit the headphones he is using. At each step, the user can adjust the level of boost (positive or negative) by adjusting the slider at the bottom. Progress through the various frequencies is noted by the bar at the top. (After finishing the preset, the user can still adjust the overall output volume using the phone's volume buttons.)

Figure 3 shows the screen for sending audio to another device. Once you reach this screen, the app will start looking for another device to send audio to (i.e. the app running on another phone). Once a match is found, that phone's description (including a random PIN code) appears in the dropdown at the top of the screen; pressing the power button will start the connection.

Outcome

In testing the app, it was quickly apparent that my test devices (a Nexus 5X and a Moto Z Play) had some hardware limitations; in particular, their microphones did not pick up distant sounds very well. Hearing that difference led me to consider my test results along two avenues:

1. How could the app work better with existing devices?
2. How might a purpose-built device improve the experience?

The app itself, while very much a prototype, shows promise. It does well at playing what the phone hears and can connect to other phones and play back their voice. There is some debugging needed in the phone-to-phone connection, but that is typical of working with wireless connections.

In March, I was able to show off the app at a local school's career day. Most, if not all, of the 4th and 5th graders I spoke to knew of classmates with hearing loss and were familiar with FM systems. The students seemed to enjoy using the app—especially having me talk into a phone from across the room.

My son, Luke, also tried the app. He immediately took to the idea of hearing through the phone, using it to explore sounds that were likely new/softer before (such as rubbing the phone against a surface or talking directly into it). Since his first interaction, Luke has repeatedly asked to use the app again. My wife and I plan to purchase an inexpensive, rugged phone and waterproof headphones so Luke can start using the app when he can't use his hearing aids.

Limitations

The first outcome of my testing was that Android does not provide enough fine-tuning for frequency response. On my two phones, the built-in Equalizer class only provides 5 frequency bands—only 3 of which cover the frequencies of a typical audiogram (6-8 data points spread from about 125 Hz to 8 MHz; for an example, see [8]). This lack of fine-tuning can be addressed by using a native sound library like Superpowered[1] to transform the output to match exactly what the user wants. A better solution, however, would be for either a phone maker or (ideally) Android itself to implement a more generic software equalizer.

Another concern is sound output: while my phones provided enough sound output for me, it was not clear if it was enough for a person with severe hearing loss to get the full benefit of the app. I purchased a sound amplifier, which boosted the output, but a device marketed towards people with hearing loss would need more sound output.

It should also be noted that Hearing Phone works far better with wired headphones than over Bluetooth. Using a Bluetooth headset adds a significant amount of lag, making wireless headphones impossible to use in a real-time hearing situation.

As mentioned above, my phones also had trouble picking up distant sounds. At close range (within a few feet), I could hear some sounds better than with my unaided ears, such as my feet

hitting the floor as I walked. More distant sounds, such as a TV playing across the room, were dim. Fixing this would mean either finding a way to plug in a microphone (problematic since the headphone jack is already occupied by headphones), using headphones that include stereo mics suited for this purpose, or buying a phone equipped with additional/different microphones. The Amazon Echo and Google Home smart speakers show what can be done with "far-field" microphones; a phone or headphones that include a wider mix of microphones would likely work much better as a hearing aid stand-in.

It's quite possible that a higher-end phone might fix the limitations I discovered. The LG V30, which is a phone marketed for both video recording and audio output, would be an interesting device to test with the app.

Cost (Cost to produce and expected pricing)

I estimate that the Hearing Phone app needs about 3 more man-months of work before release. The remaining development includes:

1. Using a library to reduce lag and allow fine-grained sound transformation based on the user's needs
2. Allowing users to manage sound presets (edit and delete them)
3. Allowing frequency adjustments on a per-ear basis (my son's hearing loss is roughly the same in both ears, but this is by no means universal)
4. Improving the reliability of the phone-to-phone connection
5. General fit-and-finish, cleanup, and testing

Much of the experience of creating the Android app would transfer to an iPhone version. Creating an iPhone version of the app ought to take a further 4-6 months.

When selling Android apps, the freemium model tends to work best (i.e., make the app free and recoup the costs with in-app purchases). I would make the basics of the app, listening to what the phone hears and creating presets, free. Connecting from one phone to another would be the in-app purchase, with a price of $4.99. I would also include a trial period so that the user could experience the feature before paying for it. iPhone pricing would likely be the same, and I would also ensure that Android phones and iPhones could be paired together.

Headphones specifically created for this app, with stereo microphones designed to hear sounds both near and far, would likely incur a premium compared to existing headphones. Such headphones would also need to be waterproof. Noise-cancelling headphones, with their extra mics to pick up background noise, would likely be a good price indicator. At the time of this writing (April 4th, 2018), Amazon has a basic set of noise-cancelling headphones for $49[9].

If we consider a phone built for people with hearing loss (and one that the Hearing Phone app could use to the greatest benefit), it would likely mean either adding far-field microphone(s) or, at the least, replacing some existing microphones. Ideally, such a phone would also come with

an equalizer with more adjustments and with work done to minimize audio latency. With Amazon Echo Dots and Google Home Minis (which include far-field microphone arrays) costing well under $100, the additional/replacement mics should not add too much to a phone's cost. It would also be good to include a larger battery, as constantly recording, playing back, and (optionally) receiving audio data will require the phone's processor to remain engaged. All told, the price difference should be less than $100. (It should be noted that additional mics and a bigger battery would also be selling points for video recording and phone longevity, as well.)

Significance

Hearing aids bring the gift of hearing to people who do not have full use of their ears. But that gift comes at a steep price, both in the cost of hearing aids and in the accessories that let you get full value out of them.

The Hearing Phone app is an inexpensive way to supplement hearing aids. For one, it uses equipment most families already have, and even if a family wishes to buy a dedicated phone and headphones it can do so at a fraction of the typical cost of hearing aids (or even hearing aid accessories). The low cost of entry means that this app can also serve as a bridge while a family saves up for hearing aids, or as a stopgap when hearing aids break or are lost.

Hearing Phone also opens new opportunities for people with hearing loss. With the right phone and headphones, a person with hearing loss can enjoy a trip to the waterpark or a rainy day without worrying about destroying a costly device. A parent, caregiver, or friend can use their phone to keep in touch with the person with hearing loss, helping guide them through crowds or areas with lots of background noise. The person with hearing loss can further customize their experience to work best with their favorite headphones.

It is possible that, with the right device, Hearing Phone could approach the usefulness of hearing aids. While a standard smartphone is likely too bulky to be used as a permanent hearing device, a device specifically designed for people with hearing loss—perhaps a smaller device that trades screen size for improved microphones and a larger battery—could one day replace hearing aids entirely.

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