Periwinkle

Where is the Sound?

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Introduction

Hearing loss is one of the most common types of disabilities and affects around 5.3% of the world population. Cochlear implants are small electronic devices implanted surgically that provide a sense of sound to a person who is hard of hearing and has difficulty recognizing speech. They are typically recommended for individuals with severe to profound hearing loss in both ears who do not benefit from traditional hearing aids.

Cochlear Implants are designed to mimic the function of a healthy cochlea (inner ear). Cochlear implants replace damaged sensory hair cells in the cochlea and usually have two parts: the external sound processor which is placed behind the ear and the internal implant that is surgically placed under the skin, attached to an array of electrodes that are connected to the cochlea.

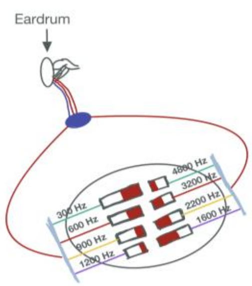

Figure 1. Microphone location

Figure 1 shows the location and the type of microphone array structure used in cochlear implants. In research on implantable cochlear implants, the source discussed how when acoustic sound pressure is applied to the eardrum, the cantilever beam along with the frequency starts to vibrate with it, each cantilever vibrates to a different frequency band in the cochlea, The microphone array resonates at a frequency from 300 Hz to 1600 Hz. The transducer then senses the eardrum vibrations and generates the required voltage output for stimulation. The highest sensitivity of the microphone sensor is 391.9 mV/Pa at 900 Hz.

For our senior design project, we created a device to track audio direction. This was an extension of our findings after talking to students from the hard of hearing community at Tufts. One of the students we talked to is a cochlear implant recipient. The idea of sound localization difficulties came up in the conversation.

Sound Localization by normal-hearing listeners

Sound localization is the ability to distinguish where different audio cues are coming from. This is important as it impacts our safety, how we communicate with others as well as our learning.

Interaural Time Difference (ITD)

Interaural time differences (ITDs) are one of the main factors that allow listeners to determine spatial location of sound sources. Because of the separation of the two ears, the path that audio cues take to reach the two differs which lead to different time of arrival of the sound wave at the two ears; this then causes ITDs. For example, if a person is speaking from the right, those with normal hearing will first receive the sound from the right ear before the left ear receives the same sound.

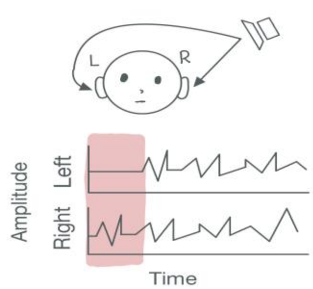

Figure 2. Interaural Time Difference

The brain uses this time difference to localize sounds in space. The range of ITDs is proportional to a person's head diameter; the bigger the diameter, the bigger the time difference is between the two ears. ITDs are binaural cues for frequencies below about 1500 Hz or for lower frequencies sounds. Lower frequency sounds have longer wavelengths and are more easily detected by the ears while higher frequency sounds have shorter wavelength and therefore can be more difficult to localize solely on ITDs alone.

Interaural Level Difference (ILD)

Interaural level differences (ILDs) are useful for higher frequency sounds. Because of how intense a sound coming in is, the ear can tell how close the sound source is. For example, a dog barking three meters from you is going to sound louder than from the same dog barking ten meters from you.

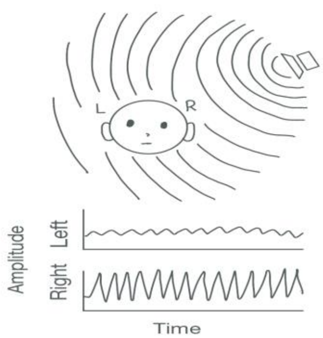

Figure 2. Interaural Level Difference

In addition, the magnitude of the audio cues can be an indicator of the direction of audio (i.e., if a person is speaking on your right, you know that they are on your right because the sound is more intense in the right ear). ILDs are frequency dependent and more helpful for higher frequencies.

Spectral Cues

ITDs and ILDs only work to localize sounds within a more general area. To precisely extract sound sources from location information, humans use spectral cues. Unlike ITDs and ILDs, which are binaural cues, spectral cues are monaural cues, which means that it is based on the spectral property of the head-related transfer function. A head-related transfer function or HRTF is used to describe a sound's spectral characteristic at the tympanic membrane.

Sound Localization by cochlear implant recipients

Cochlear implants can supply great hearing benefits to those who have hearing loss, however the sound localization problem is still present. This is especially true when in a louder setting or when many sound sources are present.

While cochlear implant users can still perceive some degree of sound localization by using ITDs and ILDs cues between the two ears, because the auditory information received is slightly altered by the implant, the information received is not as accurate as that of normal-hearing listeners. This was confirmed after talking to one of our customers we are designing our senior design project for.

Other Drawbacks of Cochlear Implants

To try to understand the experience of a cochlear implant user, it is useful to look at the drawbacks of the device. Besides sound localization issues, cochlear implants have other drawbacks, mostly in the physical hardware itself. These include the frequency of battery replacement and the risk of external damage when submerged in water. Fully implantable cochlear implant systems can rid of many of these drawbacks, but the problem with that is that it needs a reliable internal power source and an internal acoustic sensor (unlike the external sensors used currently). In addition, the main barrier to using cochlear implants is the price tag. Many people who could benefit from cochlear implants stray from the option due to how expensive the surgery is. The average cost of cochlear implants ranges from $30000 to $50000 without insurance. This makes it super inaccessible to many people who could benefit from it. Besides the cost of the implant itself, there are other costs like the cost of surgical procedures, rehabilitation, and maintenance.

Although these drawbacks make getting cochlear implants a barrier for a lot of people, there is a huge need for the device in the hard of hearing community. This is why it is important to ensure the best experience for cochlear implant recipients. A huge step towards this is sound localization.

Techniques for acoustic localization

In general, techniques for an acoustic localization include interaural time difference or interaural phase difference (IPD). Both of which we implemented in our capstone project device by using a general cross correlation algorithm (GCC). In addition, interaural level differences were also explored as we started with a magnitude response of the audio cues coming in. However, because this technique (ILD) is less accurate especially in louder environments, it has received little attention in the signal processing community.

Conclusion

While cochlear implants are effective in improving hearing quality and a person's quality of life, they are not a cure for deafness and do not restore normal hearing. Research on cochlear implants is ongoing, finding improvements to the device to hopefully one day mimic that of normal hearing.

In our project, we aim to tackle the sound localization problem in the hard of hearing community, including those with cochlear implants. The project explored phase, time and magnitude characteristics of waves coming into a device. These characteristics all reflect how normal hearing works.

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