Methods of Passive and Active Noise Cancellation

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Introduction

Headphones have quickly become one of the most widely and commonly used technologies. While streaming services have played a huge role in making the use of headphones more mainstream, the improvement of headphone technology has played an equally large role. One major area in which headphone technology has improved is noise cancelation. This paper will explain the different methods to achieve noise cancellation, including passive and active noise cancellation.

Passive Noise Cancellation (PNC)

Passive noise cancellation (PNC) is accomplished in headphones using the materials of the headphones to absorb environmental noise before it can reach the user's ear. Typically, headphones that utilize PNC are one of two designs: over-ear or in-ear headphones. Over-ear headphones create a seal around each ear using a foam ring that lines the outside of each ear cup. This design can help to block out external noise by reducing the amount of sound that enters the ear canal. The backs of the ear cups are also made from materials that are meant to absorb sound. The foam seal combined with the sound-absorbing materials result in the absorption of a significant amount of environmental noise. In-ear headphones achieve passive noise cancellation by creating a seal within the ear canal to prevent noise from entering and using noise-absorbing materials. The seal with the ear canal is created by the tips of the in-ear headphones. The goal of these tips is to mold exactly to the shape of the ear canal so that there are minimal openings for external sound to get into the ear canal. Thus, the tips are usually made from flexible rubber or plastic, or even memory foam. Some headphones, however, do not have a tip and rely solely on the shape of the earbud to block most of the ear canal opening. Though in-ear headphones create a better seal than over-ear headphones, over-ear headphones tend to have better PNC because they are much larger, meaning there is much more noise-absorbing material that can prevent noise from reaching the user's ear [1].

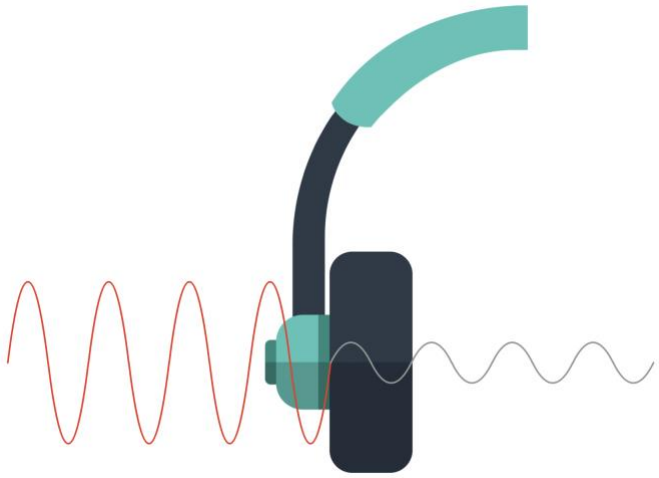

Figure 1. Passive noise cancellation diagram

Active Noise Cancellation (ANC)

Active noise cancellation (ANC) is a method that uses technology and the properties of signal interference to reduce unwanted noise from a signal. The basic principle behind ANC is that sound waves can be canceled out by an opposing sound wave with the same frequency, same magnitude, and opposite phase. This works because sound waves are just the brain's interpretation of pressure differentials in the air. When opposing sound waves meet, the positive pressure created by one wave and the negative pressure created by the other wave sum together to

result in net zero pressure. This concept is known as destructive interference. In order to implement ANC in headphones, digital signal processing (DSP) methods are used. The DSP methods listen to and filter the noise, create an inverted signal (also called anti-noise), and then play back the anti-noise through the headphone's speakers. There are three main methods of ANC used in headphones: feedforward ANC, feedback ANC, and hybrid ANC. These methods are explained in more detail in the following sections.

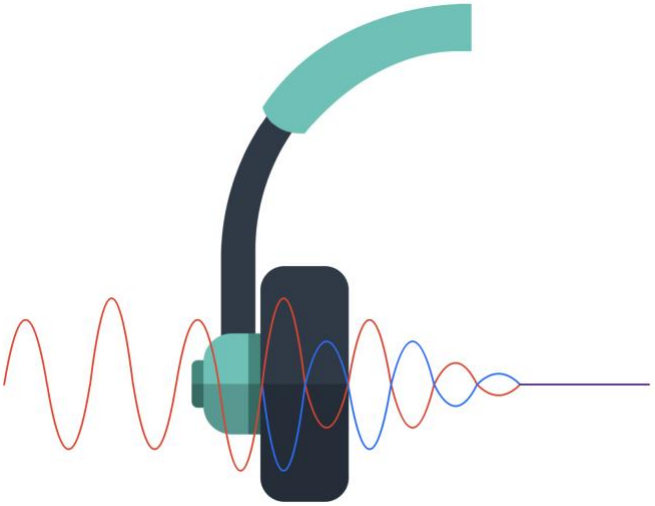

Figure 2. Active noise cancellation diagram

Feedforward ANC

Feedforward ANC is the simplest and most common type of ANC used in headphones. The feedforward approach uses one or more microphones that are placed facing outward on the backs of the headphones. The microphones pick up all the surrounding noise. This noise is then processed using DSP methods to generate the anti- noise. The anti-noise signal is then played through the headphone speakers on top of the already playing audio. The anti-noise signal cancels out the environmental noise while leaving the perceived audio signal mostly unchanged. One advantage of this method is that it requires the least DSP, allowing the ANC to have very little delay. Additionally, the placement of the microphones allows the headphones to detect the noise before it can reach the ear canal. This gives the processor slightly more time to create the anti-noise signal. One disadvantage of this method is that it is not as accurate because the headphones cannot detect how much noise made it to the ear canal. Instead, they estimate how much noise to cancel based on the frequency response of the headphones [2].

Feedback ANC

Feedback ANC is a slightly more complicated type of ANC that is also a very common method of noise cancellation in headphones. The feedback approach uses one or more microphones that are placed inside the ear cup facing toward the ear canal. The microphones pick up all the audio that made it into the ear canal. This audio includes both the audio signal from the headphones and the external noise that was not canceled by the PNC. The device audio is extracted from the microphone audio so that only the noise is left. Then, the noise can be processed and converted to an anti-noise signal to be played through the headphone speakers. One advantage of the feedback method is that the positioning of the microphones allows the headphones to detect the noise that the user hears, rather than the noise they might hear. This allows the ANC to generate a more accurate anti-noise signal that cancels more noise. One disadvantage of this method is that it requires more DSP to calculate the anti-noise signal because the noise must be separated from the audio signal being played by the headphones. This, along with the closer proximity of the microphones to the ear canal, result in a system that has more delay and a shorter window to process and play the anti-noise. Additionally, the proximity of the microphones to the speaker creates a feedback loop between the two. Thus, careful filtering and other DSP methods must be put in place to prevent the possibility of a positive feedback loop [2].

Hybrid ANC

Hybrid ANC is the most complicated of the three discussed ANC methods. This method combines feedforward and feedback ANC. Microphones are placed on the outside and inside of the ear cups. This allows the headphones to cancel the noise that is detected by the outer mics and then also cancel the remaining noise that made it into the ear canal. The main advantage of this method is that the combination of the data from the two previous methods allows for the most accurate anti-noise signal. The outer microphones detect the noise before the inner microphones, allowing for the feedforward ANC to cancel out noise before it reaches the ear

canal. Then the inner microphones allow for the feedback ANC to cancel the remaining noise. The main disadvantage of this method is that it is much more complicated to implement than either of the previous methods. The complexity is a result of the extra processing needed to ensure that the noise is not being "over-canceled" by the combination of the two methods. This would result in the noise getting amplified instead of canceled [3].

Conclusion

For our senior design project, our group's goal was to design headphones that can selectively cancel noise while allowing voices to pass through. We accomplished this by first canceling all noise and then adding the voices on top of the audio and anti-noise signal. Thus, we needed to implement some method of ANC. Given the use and constraints of this project, PNC combined with feedforward ANC was the most practical method to implement in our project. This is the simplest method and allowed for minimal interference between the microphone data and the audio played from the speakers.

References

1. A. Shalool, N. Zainal, K. Beng Gan and C. Umat, "An investigation of passive and active noise reduction using commercial and standard TDH-49 headphones," 2016 International Conference on Advances in Electrical, Electronic and Systems Engineering (ICAEES), 2016, pp. 606-609, doi: 10.1109/ICAEES.2016.7888118.

2. Kuo, Sen & Morgan, Dennis. (1999). Active noise control: A tutorial review. Proceedings of the IEEE. 87. 943 - 973. 10.1109/5.763310.

3. Y. Xiao and J. Wang, "A New Feedforward Hybrid Active Noise Control System," in IEEE Signal Processing Letters, vol. 18, no. 10, pp. 591-594, Oct. 2011, doi: 10.1109/LSP.2011.2164067.

4. B. Reshma and K. A. Kiran, "Active noise cancellation for in-ear headphones implemented on FPGA," 2017 International Conference on Intelligent Computing and Control Systems (ICICCS), 2017, pp. 602-606, doi: 10.1109/ICCONS.2017.8250533.

5. N. Zacharov, J. Ramsgaard, G. Le Ray and C. V. Jørgensen, "The multidimensional characterization of active noise cancelation headphone perception," 2010 Second International Workshop on Quality of Multimedia Experience (QoMEX), 2010, pp. 130-135, doi: 10.1109/QOMEX.2010.5516119.