Impact of Microphone Distribution for Active Noise Canceling Model

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Introduction

As noise-canceling technology continues to develop, it becomes increasingly observable and relevant in our world. Consumer audio companies have invested significantly into noise-canceling systems in flagship earbuds and headphones, demonstrating public interest and successful implementation of the technology. However, this technology has only been commonplace in retail environments within the last decade. As the hardware of noise canceling technology is iterated and improved, it will be able to support new features that simulate spatial awareness in an inorganic environment.

Active Noise Cancelling

Methodology

Active noise cancellation (ANC) is achieved by collecting environmental noise through an arrangement of microphones. Recorded audio signals are processed and inverted to be sent through a wearable audio device (headphones, earbuds, hearing aid). This inverted signal counterbalances with noise in the surrounding environment, such that "the sum of the canceling signal at [the] microphone... and the noise at [the] microphone" (1) cannot be interpreted audibly. Active noise canceling hardware also benefits from sufficient passive noise isolation, which is achieved in consumer offerings using closed-back headphones or earbuds. The blend of hardware and software isolation can eliminate up to 99.9% of background noise in retail ANC offerings.

Feedback System

ANC technology relies on feedback logic to accurately report environmental noise and generate a noise canceling signal. As environmental noise is collected by the microphone array, it is fed back through the device to determine what audio content needs to be canceled. Therefore, the quality of noise canceling is solely dependent on the audio recorded by the device's microphones. A poorly implemented feedback system "can result in amplification of the noise" (1) in the user's environment. It is important to arrange microphones in ANC effectively so that they can best capture the surrounding environment. Poor microphone arrangement can result in miniscule time delays between the microphone that may impact the quality of the noise canceled signal.

Microphone Placement

In current ANC hardware available at retail, the microphone array is responsible for simulating the flexibility and function of the human ear. Although

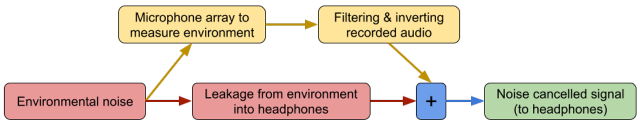

Figure 1. Block diagram of active noise cancelling (ANC) model

there are consumer offerings that claim to have multichannel audio for each ear, this is a misleading term that employs the use of audio-processing software to simulate spatial awareness: a user's perception of their environment that is not organic. The microphones "are physically attached to talkers and move with them" (3) at a location near the human ear, such that the volume of collected environmental noise closely matches what a human would hear without wearing the device. This consideration greatly improves ANC technology and its level of immersion.

When designing a microphone array for ANC, it is important to consider the types and quantity of microphones that are commonly used. Since the human ear can only hear a limited range of audio frequencies, the choices for microphones within the desired audio rage are plentiful and are low cost. Current ANC solutions generally use a stereo left and right microphone arrangement directly over the human ear. It is important to consider the significant margin of error in placing these microphones such that the environmental noise arrives at both microphones at the same time.

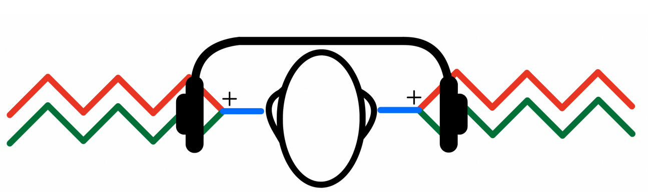

Figure 2. Visual representation of ANC signal addition with sound leakage (red) and processed microphone signal (green)

More elaborate ANC technologies can be equipped with more than two microphones, requiring more engineering power and calculations to ensure that each microphone recieves environmental noise at the same time. Products such as Apple AirPods Pro feature multiple microphones per ear that point in different directions to collect environmental noise from behind the user, improving quality of ANC in multiple directions.

Individualized Audio Processing

The human ear is fascinating in its ability to collect data on its surroundings, known as sound localization. When a sound wave reaches a user, the "differences in time and intensity help the brain to locate the direction of the source of the sound" (4). This concept is used to create a mathematical application called the head-related transfer function (HRTF) to improve spatial awareness. Applying an HRTF to ANC technology provides key information about the size of the user's head and location of their ears, such that users can better distinguish location and distance of sounds as if headphones were not being worn. The mathematical property depends on the form and shape of each user's head, therefore making HRTFs extremely unique for all users. To use this technology with noise cancellation, the environmental noise being collected must "allow the recording of all the spatial information available to the ear" (5). This can be done through binaural recording.

Binaural recording primarily employs the use of two microphones to playback audio as if it were being heard by human ears. Professional binaural recordings use ambisonic microphones that are specially designed to capture audio in a variety of positions around them. This positional data can be processed into spatialized audio files that simulate three-dimensional sound, assuming that "binaural measurements and headphone equalization steps are realized with the target listener's own ears" (5) by means of HRTFs. Given this technology, it is possible for environmental noise to be recorded and spatialized in headphones, assuming the ANC system supports a binaural microphone arrangement.

Applications of Binaural Audio

Binaural technology continues to be researched and implemented in consumer products, resulting in audio-focused, computer-driven experiences through computer software. However, its spread is limited due to the user's necessity to measure their heads and ears to generate their own HRTF. Although the audio content is still usable without applying a personalized HRTF, it is much less immersive and does not showcase the abilities of the novel technology. A popular utility used in consumer ANC systems that benefits from this technology is 'Transparency Mode'. Apple previously used proprietary Spatial Audio technology, designed using Dolby Atmos for Headphones, to simulate awareness of the environment through complex audio-processing software. However, additional sensors on their handheld products (iPhone) can collect information of a user's ears to personalize their Spatial Audio experience, effectively allowing users to generate their own HRTF for use within Apple's ecosystem. Since binaural content improves "hearing protection and speech transmission" (5) in certain noisy environments, this software feature gives ANC technology great flexibility.

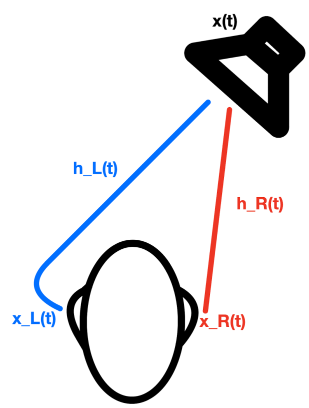

Figure 3. Visual representation of head-related transfer function (HRTF)

Technological Development

A potential area of ANC development is the use of machine learning models to improve overall noise canceling function. By analyzing large amounts of sample audio signals, it is possible that ANC could cancel out specific noises instantaneously if it can predict that they will occur. Machine learning models could be trained to distinguish certain noise patterns, including traffic, machinery, or speech, allowing ANC systems to adapt to their environment in real-time. This would allow users to personalize noise canceling for different environments, which is currently not a feature in commercial offerings. As machine learning continues to advance in scope and application, it is possible that ANC systems could predict certain undesirable noises, such as sirens or fire alarms, to protect users' ears. Therefore, it is crucial that the microphone array for an ANC system can withstand high volumes, such that unwanted audio content can be cancelled in high-pressure environments. A combination of three-dimensional audio with selective noise canceling provides endless opportunities for new technologies, including AR/VR applications or for clearer communication in noisy environments.

Conclusion

As computer power for ANC applications continues to improve, it is essential that the microphones used to capture data are reliable, well-calibrated, and arranged to best capture the user's environment. All proposed benefits of noise canceling technology are extremely dependent on the device being used and the software that it is running. Therefore, they are paramount for active noise cancelling and can drastically impact a user's experience. Although many of the proposed technologies are currently not offered by technology companies, it is evident that ANC technology is still in a state of infancy, with exciting functionality being designed and added through over-the-air updates and exciting new headphone products. This technology is greatly beneficial to its users, and will continue to provide fascinating experiences, assuming microphone arrangement remains a significant focus for designers and engineers.

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