A Study of Applied Acoustic Active Noise Cancellation and Other Active Vibration Control

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Abstract

The consumer and professional acoustics industry was fundamentally changed when Amar Bose developed the first applied and ready active noise cancellation system for headphones in 1989. Through destructive interference, the amplitude of a mechanical wave of sound can be manipulated to inaudible levels. This property of mechanical waves has been applied to the acoustics industry for a user to isolate themselves from the sounds of their environment. This is accomplished by way of a microphone within the headset detecting sounds directed at the user to then be processed and inverted efficiently to have a separate speaker within the headset play that inverted wave. The original and inverted wave then meet in the space between the separate speakers and the end of the ear canal and deconstruct one another so that the user's listening experience is almost inaudible.

This technology has advanced in quality, consistency, and cost efficiency while never evolving far beyond the original application of general to professional consumer headphone use. This is due to the nature of destructive interference, as the waves must be in perfect alignment within space in order to deconstruct one another.

There is a severe lack of documentation and research on wider applications of active noise cancellation due to the aforementioned physical hurdles of mechanical waves. Extensive research on documented niche applications of this technology, consumer applications, public raw acoustic data, as well as core calculations may lead to unexplored territory in the field of active noise cancellation in order to understand, form, and workaround the problems presented.

Context

Sound is a mechanical wave, or a wave of energy that has to travel through a medium. This property of sound means that sound waves that are touching in three dimensional space will interact with one another. Engineers harness this property for deconstructive interference, which occurs when waves are close to 180 degrees out of phase; their interaction resulting in a wave with less amplitude.

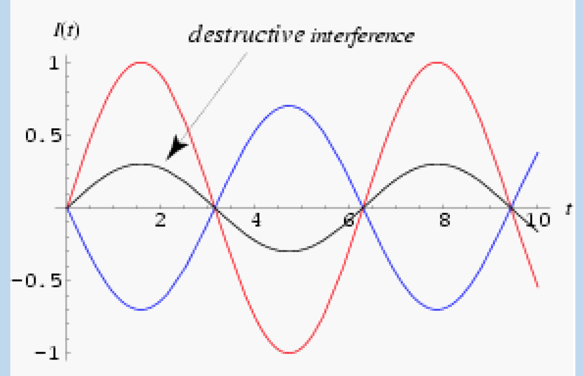

Figure 1

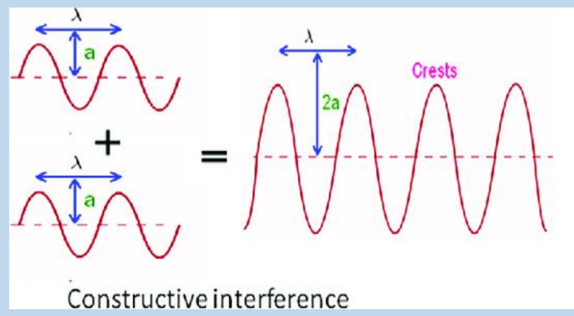

Figure 2

Even if the artificial wave created by the device is a perfect inverted replica of the original sound, if it is offset by half a wavelength or even less, there is no deconstructive interference occurring. This will result in more sound for the user than there was originally. This is called constructive interference.

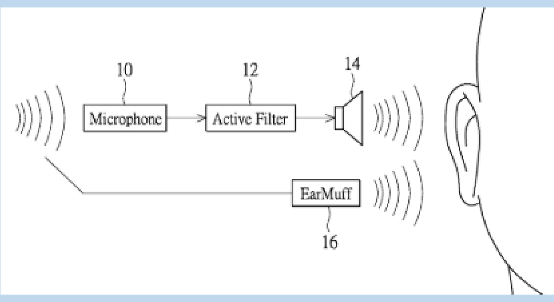

Figure 3: Simplified Headphone Apparatus

Ultrasound is sound outside of the range of human hearing, which is above 20kHz. Going above this range results in interesting properties. The higher the frequency above 20kHz, the less sound propagates in all directions. A high enough frequency ultrasound driver can produce a sound that acts like a laser. This very precise wave of energy is used for non invasive, radiation free, precise imaging for pregnancies and other medical imaging. When sound hits a surface such as a human hand or a wall, some of the energy is absorbed by the object and whatever energy is left is reflected by that object. The resulting reflected wave has a lower frequency. This means that an ultrasound driver can send a sound to a very accurate location, and at that location produce a noise that can be heard by humans.

Findings - Research

Window/Duct

- Speaker driver is attached to a flat surface
- Vibrates the surface itself rather than a traditional speaker cone
- Benefits of this include applications on a larger scale as well as more efficient for lower frequency, droning sounds
- Requires much less computational power when compared to traditional multi-source options

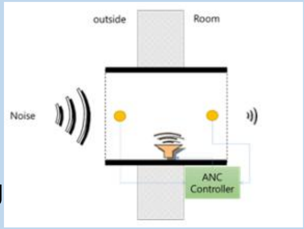

Figure 4: Window System

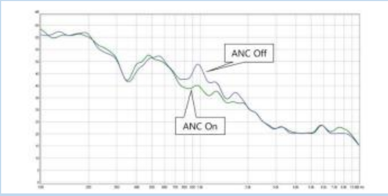

Figure 5: Averaged spectrum at the error microphone with and without ANC

Single Source Room Scale

- Computationally demanding (opportunities for AI to reduce source error)
- Very specific setup required
- Only tested on artificially generated noise and simple aircraft noise

Multi-Source Room Scale

- Less developed and tested
- Involves a much more niche setup/application but requires less computational power when compared to the algorithm used for single source

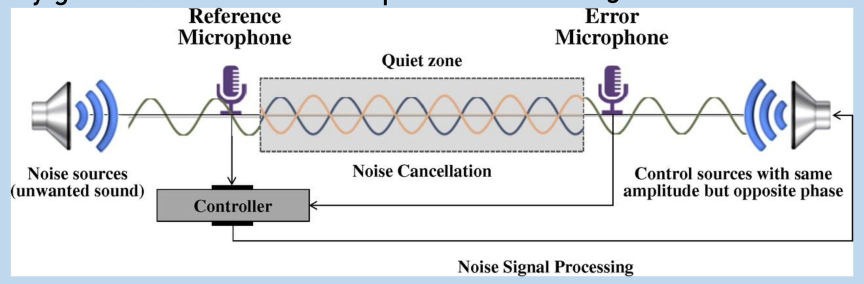

Figure 6

Ultrasound: Parametric

- Series of ultrasonic drivers
- Computer algorithm made to have the ultrasonic sound waves hit an object and constructively interfere in amplitude while reducing frequency to be within hearing range
- The laser like property of high frequency sound makes this possible, because even over longer distances the waves stay in the same phase
- Individual ultrasonic drivers do not produce high amplitude, but when the energy of each wave is added it creates a much more encompassing sound

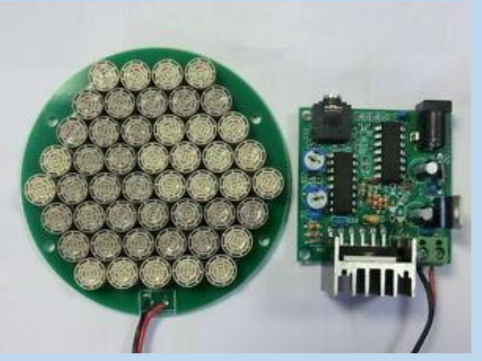

Figure 7: Ultrasonic drivers in parametric series attached to processor

Findings – Use Cases

Ultrasound Spotlight Speaker

- Acouspade, SoundLazer
- Opposite of active noise cancelling
- Involves constructive interference
- Only used in high end showrooms and DIY projects

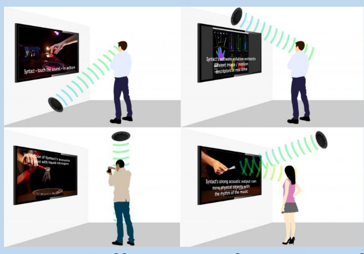

Figure 8: Different Configurations for Acouspade

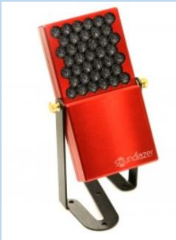

Figure 9: SoundLazer

Engines

- Very rare
- Automobile engine vibration control
- Diesel engine exhaust noise control on stationary equipment
- Helicopter cabin noise
- Requires high technical skill to set up and calibrate
- Unsatisfactory results
- Uses simple speaker drivers and algorithms

Muzo

- Raised $532,666 on Kickstarter
- Uses a driver to vibrate the window and actively cancel all noise coming through from the outside
- Example of single source room scale
- Resulted in adding to overall noise
- Remarketed to be a simple Bluetooth speaker

Figure 10: Muzo

Ideal Current Use Cases

- Low frequency sounds
- Minimal sound fluctuation
- Controlled space
- Speakers are not moved, either throughout the room or vibrated
- Material that encases sound is able to dampen
- Less computational power, less technical skill to setup, minimal manual recalibration

Implications

Based on this literary survey, many researchers and optimistic consumer product manufacturers have recognized the power of active noise cancellation in the consumer and professional industry. There have been attempts at using existing technology in other use cases, which seemed to fail such as in the case of applying simple speaker drivers to accomplish room scale active noise cancellation. The more compelling research was that of prototype active noise cancellation techniques that are not yet widespread throughout the industry.

There are many roads to get to room scale or large scale machinery active noise cancellation, but none are efficient enough to be cost effective or have a user satisfying experience.

There is reason to backtrack and study multi-source based active noise cancellation based on the scholarly articles. The industry seemed to favor single source applications due to its cost effectiveness and user experience, following in the footsteps of the traditional active noise cancelling headphones. However, the single source model lacks in reliability and is not applicable to the broad use case in which the researchers and companies seemed to hope it would apply to. While a multi-source system is much more technically demanding, there was little to no research done on the subject aside from simple undergraduate projects.

Parametric ultrasonic speakers were included in the study due to the potential they have for the future of active noise cancellation. Every company who mass produces these parametric speakers uses it for it's most obvious use case, which is to create a beam of sound to be more private in a public setting while not requiring a device close to the user's ears. The precision of ultrasonic drivers has not been applied to active noise cancellation, or deconstructive interference. There were no notable sources which even suggested this application of the technology.

Extremely high frequencies, past that of even traditional ultrasonic drivers, could be used in a lab setting. In a very controlled environment such as enclosed equipment, a multi-source system could be established which keeps the stationary, small sample vibration free and reduces visual noise for the digital microscope sensor.

References

"#SL-01." *Sound Lazer*, www.soundlazer.com/product/sl-01-open-source-parametric-speaker/.

A. V. Oppenheim, E. Weinstein, K. C. Zangi, M. Feder and D. Gauger, "Single-sensor active noise cancellation," in *IEEE Transactions on Speech and Audio Processing*, vol. 2, no. 2, pp. 285-290, April 1994.

"Acouspade - Mounting Options." *Ultrasonic Audio*, Ultrasonic Audio Technologies, ultrasonic-audio.com/products/acouspade-directional-speaker/.

"Audio Spotlight Museums and Galleries." *Audio Spotlight*, Holosonics, 2018, www.holosonics.com/applications/museumsandgalleries.

Butterworth, Brent, and Lauren Dragan. "The Best Noise-Cancelling Headphones." *The Wirecutter*, 22 Oct. 2019, thewirecutter.com/reviews/best-noise-cancelling-headphones/.

Hansen, Colin H. *Understanding Active Noise Cancellation.* Taylor and Francis Group, 2001.

Hirnyj, Danylo. "Noise-Cancelling Headphones." *University of Illinois*, 2012.

Huang, Chih-Ying. *Calibration System for Active Noise Cancellation and Speaker Apparatus.* 3 July 2018.

Molesworth, Brett R.C., et al. "The Use of Noise Cancelling Headphones to Improve Concurrent Task Performance in a Noisy Environment." *Science Direct*, 15 June 2012, www.sciencedirect.com/science/article/abs/pii/S0003682X12001752.

"Muzo." *Celestial Tribe*, 2019, www.celestialtribe.com/product-page.

Norris, Woody. "Speakers Create a Spotlight of Sound with Ultrasonics." *Machine Design*, 6 Mar. 1997, www.woodynorris.com/Successes.htm.

Oh, Wongeun. "An Experimental Study on the Simple Active Noise Control Windows." *National Research Foundation of Korea (NRF)*, Innovative Engineering Technologies, 2016, pp. 87–90.

Zangi, K.C. "A New Two-Sensor Active Noise Cancellation Algorithm." *IEEE Xplore*, 30 Apr. 1993, ieeexplore.ieee.org/abstract/document/319310.