Active Noise Control Research Plan

# Introduction

Active Noise Control (ANC) refers to the process whereby one or more “anti-noise” signals are reproduced by loudspeakers in an attempt to reduce or eliminate certain undesired sounds in an acoustical environment. The term “active” generally refers to systems where the cancellation is done using sound pressure waves in the physical environment. Some other forms of noise control are:

* passive noise control, through the use of acoustical materials in the environment
* adaptive noise cancellation – where noise is removed electronically, sometimes using similar algorithms as in active noise control

A great deal of related work has been done on “adaptive noise cancelling”, which may operate “offline”, purely in the mathematical or electronic realm.

This document describes a plan for research into active noise control. A key paper in the area was published by Widrow in 1975 [WID1975], and used the stochastic gradient algorithm to remove a noise source based on a noise reference signal, where the system function between noise reference signal and the noise component at the signal source may be time varying. The stochastic gradient algorithm allowed the canceller to track the time varying system function. Widrow’s application was adaptive noise cancellation, not active noise control, but the algorithm has been widely used as the basis for active noise control.

A survey of various published methods for active noise control has recently been published in [KAJ2012]. That survey cites [MOR1980] as the first paper describing the so-called “Filtered-x LMS” algorithm, which is capable of handling the non-ideal dynamics of the canceller output transducer, and the error signal input transducer. A more recent survey is provided in [GEO2013], which emphasizes non-linear filtering techniques.

Neural network based techniques for ANC were reported in [SAL2014].

Although a great deal of the work on active noise control has involved theory and simulation, a number of specific applications have been published. In 2008 a system for cancelling acoustical noise generated by an MRI medical imaging device was described in [RAM2008]. The use of ANC for reducing noise in passenger trains was investigated, and described in [KAS2013].

# Questions To Be Addressed

I am particularly interested in applications of active noise control, and my goal would be to produce working systems. Although I am interested in exploring algorithmic issues like dealing with ill-conditioned matrix inversion and error accumulation I might be more effective in focusing on architecture and implementation. I have not seen many hardware implementations (recently [THIL2015] implemented a 16-tap filter in an FPGA), but I’d like to consider whether there is functional value in implementing thousands of taps, at high sampling rates. If so, then full-custom chips are warranted, and architecture becomes an interesting avenue of investigation.

Some possible questions that I’d like to research:

* Can we selectively remove broadband amplified ambient sounds for certain listeners in a venue hall, where the acoustical environment between the primary transducers (loudspeakers) and the listener may change rapidly due to motion of people in the environment, or motion of the listener. If this is possible, **what sample rates are necessary, and what filter order is necessary**? **What can be done to minimize the cost and power of this solution**? We imagine that a reference signal for the primary undesired sound can be distributed to the certain listeners via wireless transmission. **What issues are involved, regarding non-constant delays, or lost data, in this path**?
* Would there be value in developing a noise-cancelling microphone that uses active noise control at the microphone to increase the dynamic range (by nulling a very high power interferer? Work has been done in using adaptive processing of microphone signals in helicopter cockpits, but I am not aware of any system using active noise control at the microphone for dynamic range expansion. Again, speed of adaptation may be important here.
* Can we selectively remove or reduce the sound levels of components of a film sound track for certain listeners with in-ear hearing aids? For example, using wireless transmission, can the music and effects tracks be reduced for certain listeners with hearing aids, which allowing the dialog track to have normal, or increased volume? Something along these lines was taught in a US Patent [VAU2006].
* To improve the experience of hearing aid users, can we reduce the levels of undesired sounds, by using wireless transmission of noise references (e.g. background music, or other noise sources such as background music).
* Consider a high-rise apartment building in a city like Manhattan. The living experience can be significantly degraded by the road noises from ground level. Is it feasible to use wireless transmission from remote sensors that receive noise signals, and cancel out noise over a broad area of an apartment, by exciting an array of transducers mounted on window panels? If so, how dense must the transducer array be to get effective cancellation? This was investigated in [YU2007].

# Problem Formulation



**Figure 1: Stylized System Concept for Active Noise Control Application**



**Figure 2: Block Diagram of Mathematical Model for ANC**

A stylized application scenario is depicted in ***Figure 1*** and a block diagram of a mathematical model for ANC is shown in ***Figure 2***. Although, in general, ANC may be realized as a Multiple Input-Multiple Output (MIMO) system, the mathematical model is shown for only a single input and single output, for simplicity.

The basic problem formulation is determination of the canceller coefficients, w(n) to minimize the power of the heard signal e(n). Since the undesired signal, x(n), is generally considered to be uncorrelated with the desired signal, d(n), the canceller will be unable to affect the level of d(n), and will operate in such a way that c(n) tends to be the “anti-noise” for x\_(n). This leaves the desired signal, d(n), unaltered and less cluttered by the desired signal.

Mathematically, we represent the most recent n samples of the undesired sound by the vector , where

where N is the order of the canceller (number of taps in the canceller is N). We represent the coefficient values of the N taps of the canceller filter by the vector . So we have:

Ignoring the effects of the headphone speakers, and the microphone the value of that minimizes both the statistical power and sum of squared samples of the error sequence is given by:

For the statistical interpretation R is the covariance matrix of , and P is the cross-correlation vector between and . For the least-squares approach

# Summer 2015 MUSE Goals

The work performed by the two MUSE program students will lay the groundwork for future investigations into ANC in terms of model development and a scripted experimental framework, and a hardware prototype to explore some of the basics of acoustics and sound reproduction.

# References

[GEO2013] George, Nithin V., and Ganapati Panda. "Advances in active noise control: A survey, with emphasis on recent nonlinear techniques." *Signal processing* 93.2 (2013): 363-377.

[KAJ2012] Kajikawa, Yoshinobu, Woon-Seng Gan, and Sen M. Kuo. "Recent advances on active noise control: open issues and innovative applications." *APSIPA Transactions on Signal and Information Processing* 1 (2012): e3.

[KAS2013] Rutger Kastby, Claes. "Active control for adaptive sound zones in passenger train compartments." (2013).

[MOR1980] Morgan, Dennis R. "An analysis of multiple correlation cancellation loops with a filter in the auxiliary path." *Acoustics, Speech and Signal Processing, IEEE Transactions on* 28.4 (1980): 454-467.

[RAM2008] Ramachandran, Venkat R., Issa Panahi, and Eduardo Perez. "Active reduction of high-level acoustic noise on a fMRI test-bed using labview and FPGA platforms." *Acoustics, Speech and Signal Processing, 2008. ICASSP 2008. IEEE International Conference on*. IEEE, 2008.

[SAL2014] Salmasi, Mehrshad, and Homayoun Mahdavi-Nasab. "Evaluation of Neural Networks Performance in Active Cancellation of Acoustic Noise." *Majlesi Journal of Electrical Engineering* 8.4 (2014): 1-7.

[THIL2015] Thilagam, S., and P. Karthigaikumar. "Implementation of adaptive noise canceller using FPGA for real-time applications." *Electronics and Communication Systems (ICECS), 2015 2nd International Conference on*. IEEE, 2015.

[VAU2006] Vaudrey, Michael A., and William R. Saunders. "Voice-to-remaining audio (VRA) interactive hearing aid and auxiliary equipment." U.S. Patent No. 6,985,594. 10 Jan. 2006.

[WID1975] Widrow, Bernard, et al. "Adaptive noise cancelling: Principles and applications."*Proceedings of the IEEE* 63.12 (1975): 1692-1716.

[YU2007] Yu, Xun, et al. "Active control of sound transmission through windows with carbon nanotube-based transparent actuators." *Control Systems Technology, IEEE Transactions on* 15.4 (2007): 704-714.