Active Noise Control

Digital Signal Processing Project
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***Abstract*—Active Noise Control, also known as Noise Cancellation is a signal processing technique to reduce unwanted noise by adding another sound so that the other noise cancels out the first. It is achieved by introducing a canceling (anti-noise) wave through an appropriate array of secondary sources. These secondary sources are interconnected, through an electronic system, using a particular signal processing algorithm for the noise cancellation scheme. Our project is to build a noise canceling system by Adaptive Filtering Algorithms and compare the results.**

***Index Terms*—Adaptive Algorithm, Active Noise Control, Noise Cancellation, Least Mean Squares Algorithm, Filtered-x LMS Algorithm**

I. Introduction

IN electronics, noise is any random, unwanted fluctuation in electric signal.

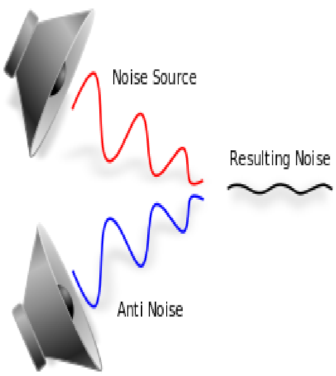

Fig.1 Active Noise Reduction

Certain videos we watch or speeches that we listen have a lot of background noise which affects our understanding of the actual content. As a part of this project, Adaptive Filtering Algorithm is used to cancel the effect of noise. Adaptive filter adjusts the coefficients of the transfer function according to the algorithm driven by an error signal. There are certain benefits of Adaptive Filters which include:

1) Works good for real-time applications and less computational complexity per iteration.
2) They improve their performance during operation by learning statistical characteristics from current signal observations.

One of the important applications of Adaptive Filter is Interference Cancellation. Active Noise Control System is an application of Interference Cancellation. There are three modules of Adaptive Filters:

1) Filtering Structure - Determines the output from the given input signals, the weights w_k (vector of weights which control the filter at any time t) are adjusted, the filters (mainly digital) can be linear (FIR or IIR) or non-linear.
2) Performance Parameters - these parameters are used to derive the adaptive algorithm and the value of these parameters have an effect on the weights.
3) Adaptive Algorithm - the algorithm modifies the associated weights to improve performance.

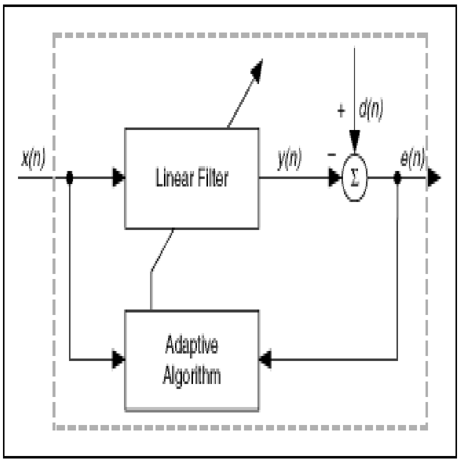

Fig.2 LMS Algorithm

LMS is a gradient descent method in which the filter adapts based on the error at current time instant. The equation of LMS filter is given below:

$$w(n+1) = w(n) + \mu e(n)x(n)$$

μ is step-size parameter, $w(n)$ is the weight vector

$$e(n) = d(n) + w(n)r(n)$$

where $r(n)$ is convolution of $g(n) * x(n)$.

II. Literature Review

There are various research papers for Active Noise Control and Adaptive Filtering Algorithms. A few of the papers have been reviewed.'Adaptive Filtering - Theory and Applications' by Bermudez gives clear understanding of Adaptive Filtering and its various applications, mathematical models and algorithms.
'Active Noise Cancellation Project' project is to build a Noise-cancelling headphone by means of active noise control. Essentially, this involves using a microphone, placed near the ear, and electronic circuitry which generates an "antinoise" sound wave with the opposite polarity of the sound wave arriving at the microphone. This results in destructive interference, which cancels out the noise within the enclosed volume of the headphone. This report will demonstrate the approaches that we take on tackling the noise cancellation effects, along with results comparison. One paper 'Hybrid Feedback System' investigates the robustness of a hybrid analog/digital feedback active noise cancellation (ANC) headset system. The digital ANC systems with the filtered-x least-mean-square (FXLMS) algorithm require accurate estimation of the secondary path for the stability and convergence of the algorithm. This demands a great challenge for the ANC headset design because the secondary path may fluctuate dramatically such as when the user adjusts the position of the ear-cup. In this paper, we analytically show that adding an analog feedback loop into the digital ANC systems can effectively reduce the plant fluctuation, thus achieving a more robust system. The method for designing the analog controller is highlighted. A practical hybrid analog/digital feedback ANC headset has been built and used to conduct experiments, and the experimental results show that the hybrid headset system is more robust under large plant fluctuation, and has achieved satisfactory noise cancellation for both narrowband and broadband noises.
'FXLMS Algorithm for Feed forward Active Noise Cancellation' . This paper explain the feed forward FXLMS algorithm for active noise control and the noise worked here are sinusoidal tones bellow 200 Hz ,computer fan noise and ceiling fan noise .Mat lab implementation of Feed forwad FXLMS algorithm is done and result is compared for different convergence factor and different filter length of control filter.

III. Variants of LMS Algorithm

As the LMS algorithm does not use the exact values of the expectations, the weights would never reach the optimal weights in the absolute sense, but a convergence is possible in mean.
If μ is chosen to be large, the amount with which the weights change depends heavily on the gradient estimate, and so the weights may change by a large value so that gradient which was negative at the first instant may now become positive. And at the second instant, the weight may change in the opposite direction by a large amount because of the negative gradient and would thus keep oscillating with a large variance about the optimal weights. On the other hand if μ is chosen to be too small, time to converge to the optimal weights will be too large.
However, for active noise cancellation, LMS Algorithm may not be good enough. So a modified LMS algorithm called Filtered-x LMS algorithm is developed which included secondary path estimates, is computationally simple and the convergence speed is slow. There are other algorithms also like FuLMS and FnLMS. FXLMS algorithm is discussed in this section.

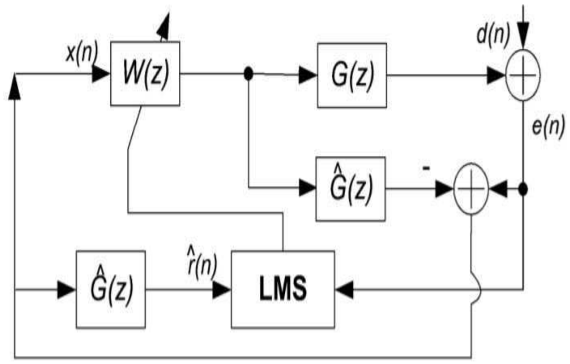

Fig.3 Block Diagram of Active Noise Control using FX-LMS

The block diagram for ANC has been shown in Fig. 1 where $d(n)$ is the noise to be canceled $x(n)$ is the input signal and $e(n)$ is the error signal. $W(z)$ is the transfer function which produces weights for the input data, $G(z)$ is the transfer function for secondary path (from where anti-noise signal is sent). The FXLMS Algorithm weight update equation is

$$w(n+1) = w(n) + \mu e(n)x(n)$$

μ is step-size parameter, $w(n)$ is the weight vector

$$e(n) = d(n) + w(n)r(n)$$

where $r(n)$ is convolution of $g(n) * x(n)$.
The secondary path can be estimated using either on-line or off-line techniques. For FXLMS Algorithm, off-line estimation is used. We send a sequence of training data to estimate $G(z)$ before the setup of noise cancellation. Its better to train the filter with white noise. But because of the limited number of coefficients of the filter, the filter will not converge to a stable state when training with white noise. Hence, we just train the filter with 200Hz sine waveform.
To make the system more stable, we change the equation as:

$$w(n+1) = a * w(n) + \mu e(n)x(n) \text{ where a¡1}$$

By introducing the parameter a, we can control the rate of weight updation over time. The value of μ should not be too large (then it will not converge or may diverge) as discussed earlier.
Another variant of LMS is FuLMS (Filtered U LMS) Algorithm. In this, we provide feedback for cancellation. When feedback is present, the solution of adaptive filter is an IIR function with poles and zeros. However, there can be disadvantages - IIR filter instability, convergence may be slow. In the results section, FuLMS Algorithm is implemented and results are shown.

IV. Previous Results

In this section, the basic implementation of LMS Algorithm is done on a sine wave with random noise as input signal. This result removes noise when it is added to a signal. Real-time noise is not removed using this. Further results for Active Noise control are discussed in the subsequent sections. The MATLAB simulation of LMS Algorithm is shown below:

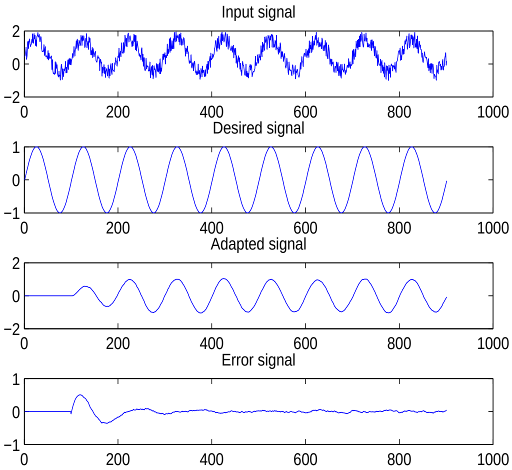

Fig.4 LMS Algorithm Implementation

There are different algorithms for Active Noise Cancellation. Comparison table of Adaptive Algorithms and LMS Algorithms are shown below in Fig. 5.

Algorithm	LMS	N-LMS	RLS
Definition	Minimizing MSE	Variant of LMS, normalizing with the power of input	Recursively minimize the MSE
Stability	Less Stable	Stable	Highly Stable
Convergence Rate	Low	Higher than LMS	Higher than LMS and NLMS
Complexity	Less complex	Complex	High complexity

Algorithm	FxLMS	FuLMS
Definition	The input to the error is filtered by secondary path estimate	Tries to adapt coefficients of an IIR filter
Stability	Stable as compared to FuLMS	Less Stable
Convergence Rate	Slow	Higher than FxLMS

Fig. 5 Comparison of Adaptive LMS Algorithms

V. Final Results

FxLMS Algorithm is implemented on random noise - generated in MATLAB. The two graphs show the error adaption and noise separation.

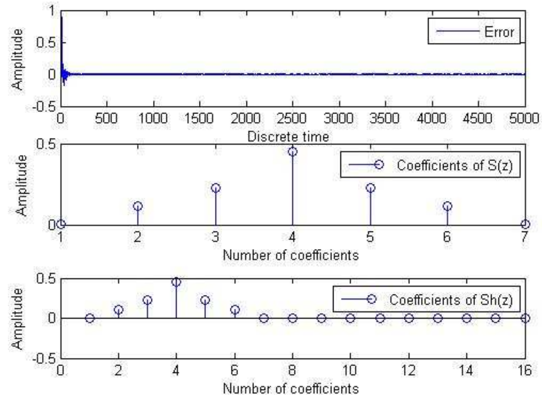

Fig.6 Error Identification

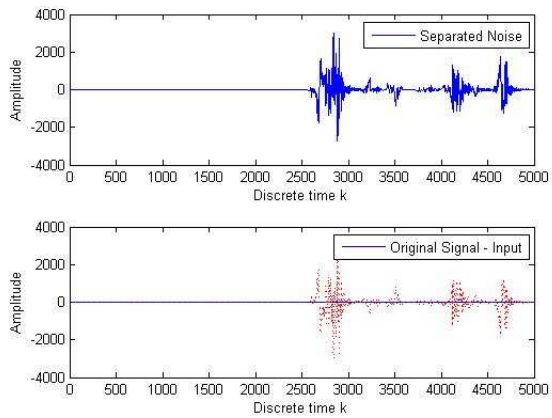

Fig.7 Noise Separation

The other result includes the comparison between two adaptive algorithms - FxLMS and FuNLMS.

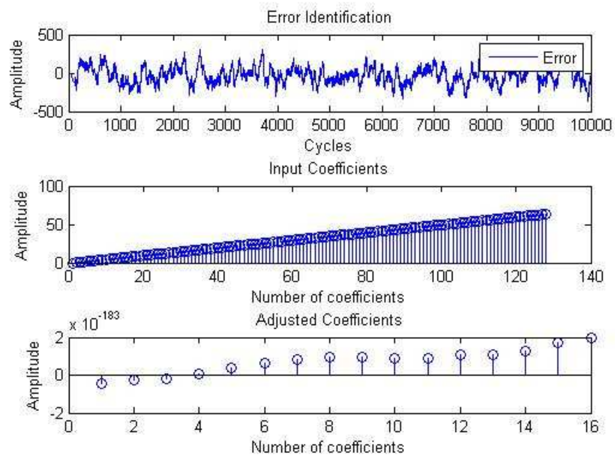

Fig.8 FxLMS Code for 16 coefficients

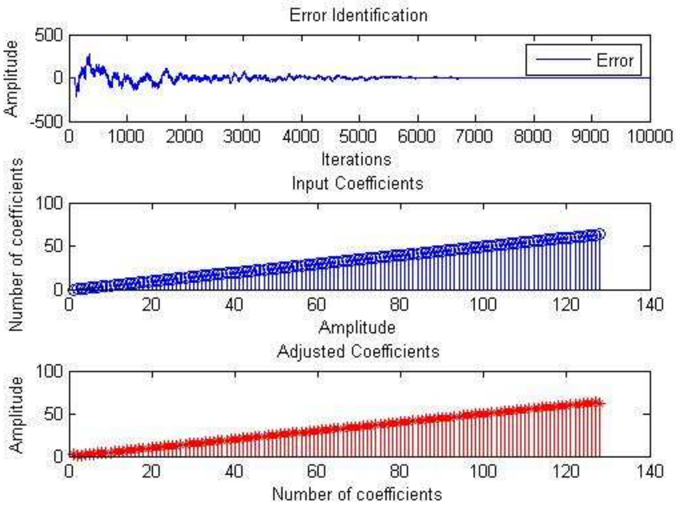

Fig.9 FuNLMS Algorithm Implementation

FxLMS Implementation on Real data - This data is recorded in real-life scenario.(A television audio) is added with random noise and then FxLMS is performed on that combined data to remove the noise and get the audio file back.

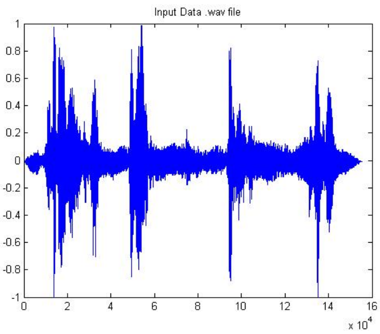

Fig.10 Input signal

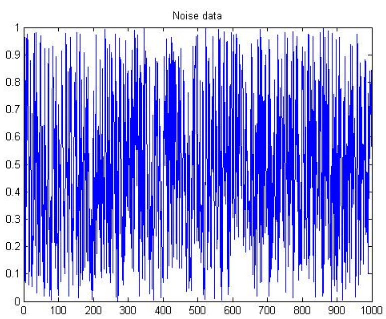

Fig.11 Noise signal

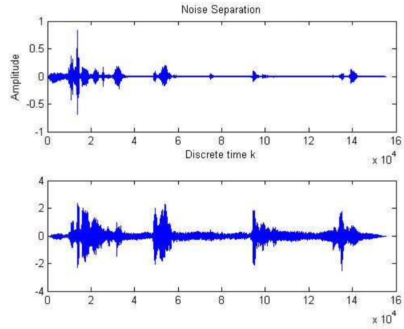

Fig.12 Noise Residue

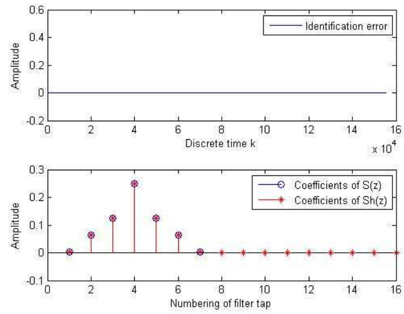

Fig.13 Error Identification

VI. Discussion - Interpretation, Opportunities, Innovation

1) Real-time signals work only when there is adequate hardware for implementing LMS Algorithms and its variants.
2) Moreover, FuLMS algorithm is better but is computationally complex than FxLMS.
3) Hardware implementation can be done for Active Noise Cancellation with desired hardware and getting the real time noise.

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