Deep Learning-Based Adaptive Noise Cancellation for Speech Signals in Low SNR Environments

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***Abstract*—In speech communication systems, obtaining desired signal from dialogue signal that is polluted by noise, using digital filter noise minimization is a widely known technique. This is accomplished by adaptive filter algorithms, in detail, this project focused on LMS and NLMS Algorithms. The purpose of adaptive noise drop is to get an estimation of the signal of noise and to deduct it from the noisy signal and hence upgrade the quality of the signal.**
For this purpose, the filter utilizes a flexible algorithm to alter the worth of the filter coefficients, so that it obtains a good estimate of the signal after each repetition. The performance of the system is evaluated by the impacts of different factors such as: - number of samples, amount of filter coefficients, step size, and input noise level. Finally, the performance of the algorithms in different cases is verified by simulating noise reduction ratio (NRR) by MATLAB platform.

***Index Terms*—Adaptive systems, Adaptive Noise Canceller, LMS, NLMS, NRR**

I. INTRODUCTION

In speech (voice) communication systems the desired signals are mixed with additive noise signals. To filter out the desired speech signal from signal corrupted by noise signal using adaptive digital filtering. The process of Extracting desired signals by this method is known as Adaptive Noise Cancellation (ANC). Noise is a public nuisance. It has an adverse psychological effect on living beings. Noise causes mental strain or tiredness, thus creating an inefficient working environment; continued noise coverage makes temporary or permanent loss of hearing.
Acoustic difficulties in the environment are gaining consideration because of the marvelous growth of technology that has led to noisy engines, heavy machinery, pumps, high speed wind buffering and many other noise sources. Experiencing to high levels of sound causes damage to human from the physical and psychological aspects. Noise pollution is another great contributor to the environmental hazards that the world is encountering these days. Together with having a negative impact on the environment, extreme noise can cause health difficulties.

The problem of controlling the level of noise in the environment has been the focus of tremendous amount of research over the years. Statutory legislations are being enforced on industries to make them strictly follow the ceiling on the maximum noise level. However, as long as the quest for larger and more powerful machinery continues, the noise pollution level will be on the rise. Due to these reasons, noise control has gained considerable importance in recent years. Acoustic Noise Control conventionally includes passive methods such as enclosures, barriers and silencers to weaken noise. These methods use either the idea of impendence change or the energy loss due to sound captivating materials.

These approaches are though not operative for low frequency noise. A technique to overwhelm this tricky is Active Noise Cancellation (ANC), which is sound field alteration using electro acoustic means. Many researchers have proposed different definitions of noise as a result of its broad category of existence. In general, the most common definition states- "Noise is arbitrary, unwanted electrical energy that enters the communications system through the communicating medium and obstructs with the conveyed message.
However, some unwanted signal is also generated in the receiver." Before initiating the study on noise reduction, it is recommended to overview noise as the

starting point. Noise can be simply stated that disturbance in the signal due to unwanted signal. The signal from any source that interfere the signal under consideration is termed as noise signal. Some common examples of noise signals are the sound from mechanical devices, biological creatures, natural phenomenon (lightening, thunderstorm etc.). The noise from the surrounding mixes with the signal and disorients its information. This effect does not need noise signal to be noisy enough to be recognized by human ears. Ultrasound noise, radio waves (for example) too interfere with signal.

In contrast with human intelligence machines cannot simply deduce noise and eliminate it. The noise prevention methods cannot be very effective since, two signals of different phase for two different receivers are noise for each other. In another words, the activity for one system produces signals that are noise for another system. Some examples of noise from day-to-day activities. The effect of noise cannot be explained as the magnitude of noise is responsible for it. In this scenario, the study of noise elimination techniques becomes a crucial share of modern signal processing systems.

II. PRINCIPLES OF ADAPTIVE NOISE CANCELLATION:

The principle of adaptive noise cancellation (ANC) is based on the idea of removing unwanted noise from a signal by generating an estimate of that noise and subtracting it from the corrupted signal. It relies on the concept of destructive interference, where two similar noise signals cancel each other when one is inverted and added to the other. In a typical ANC system, there are two inputs: a primary input that contains the desired speech signal mixed with noise, and a reference input that contains noise correlated with the unwanted noise in the primary signal. The system uses an adaptive filter to process the reference noise and produce an output that closely matches the noise component in the primary signal.

Adaptive Noise Cancellation works on the principle of destructive interference, where an estimate of noise is generated and subtracted from the noisy signal to recover the desired signal.

We assume:

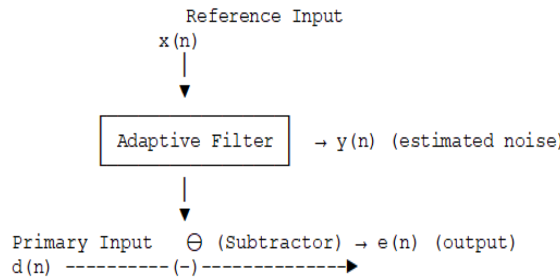
- A primary input:

d(n)=s(n)+n0(n)d(n) = s(n) + n_0(n)d(n)=s(n)+n0(n)
where
s(n)s(n)s(n) = desired speech signal
n0(n)n_0(n)n0(n) = noise corrupting the speech

- A reference input:

x(n)≈n1(n)x(n) \approx n_1(n)x(n)≈n1(n)
where n1(n)n_1(n)n1(n) is correlated with n0(n)n_0(n)n0(n)

Block Diagram of ANC System



Explanation:

- The adaptive filter processes x(n)x(n)x(n) to produce y(n)y(n)y(n), an estimate of noise.
- This estimate is subtracted from d(n)d(n)d(n).
- The output:

e(n)=d(n)−y(n)e(n) = d(n) - y(n)e(n)=d(n)−y(n)

III. METHODS

Adaptive Noise Cancellation (ANC) can be implemented using several methods, broadly classified based on signal processing approach, adaptation algorithm, and system structure. Each method differs in how it models noise, updates parameters, and handles real-world conditions.

1. Least Mean Squares (LMS) Method

Least Mean Squares Algorithm

- Most widely used ANC algorithm
- Updates filter coefficients using gradient descent

Update equation:

w(n+1)=w(n)+μe(n)x(n)\mathbf{w}(n+1) = \mathbf{w}(n) + \mu e(n)\mathbf{x}(n)w(n+1)=w(n)+μe(n)x(n)

Features:

- Simple and low computational cost
- Suitable for real-time systems

Limitations:
- Slow convergence
- Sensitive to step size

2. Recursive Least Squares (RLS) Method
Recursive Least Squares Algorithm
- Minimizes weighted least squares error

Features:
- Faster convergence than LMS
- Better tracking of time-varying noise

Limitations:
- High computational complexity
- Requires more memory

3. Normalized LMS (NLMS)
- Variant of LMS with normalization

w(n+1)=w(n)+μ‖x(n)‖2e(n)x(n)\mathbf{w}(n+1) = \mathbf{w}(n) + \frac{\mu}{\|\mathbf{x}(n)\|^2} e(n)\mathbf{x}(n)w(n+1)=w(n)+‖x(n)‖2μe(n)x(n)

Advantages:
- Improved stability
- Faster convergence than LMS

IV. RESULTS

The performance estimation of adaptive noise minimization using Least Mean Square (LMS) and Normalized Least Mean Square (NLMS) algorithms are explained in detail. The performance is studied with changing some factors includes: step size, number of filter coefficients, input noise level and number of samples. The noisy signal (speech signal with random noise) is given as input to system and the adaptive noise chancellor adjusting the filter parameters to estimate the noise which is correlated to the noise corrupting signal given through primary input to the system. Finally, the output of adaptive noise chancellor is subtracted from primary output giving the signal almost equivalent to the input desired signal (recovered signal). All the outcomes are found by Matlab simulations.

Deep learning–based adaptive noise cancellation methods generally show:
- Significant improvement in speech quality

Compared to traditional techniques (like LMS or Wiener filters), deep models (e.g., CNNs, RNNs, or LSTMs) better reconstruct clean speech from very noisy inputs.
- Higher SNR gains

Many studies report improvements of 5–15 dB in SNR, especially in extremely noisy conditions (e.g., 0 dB or −5 dB input SNR).
- Better perceptual quality

Metrics like:
- PESQ (Perceptual Evaluation of Speech Quality)
- STOI (Short-Time Objective Intelligibility) usually improve noticeably, meaning the speech sounds clearer and is easier to understand.
- Robustness in low SNR conditions

This is the biggest advantage: deep learning models outperform classical filters particularly when noise is strong and non-stationary (e.g., traffic, crowd noise).

V. CONCLUSION

Deep learning–based adaptive noise cancellation methods provide a clear advancement over traditional signal processing techniques for speech enhancement in low SNR conditions. By leveraging models such as convolutional and recurrent neural networks, these systems can learn complex, non-linear relationships between noisy and clean speech signals, enabling more effective noise suppression.

The key conclusion is that these approaches:
- Substantially improve speech intelligibility and quality, even when noise levels are very high
- Adapt better to non-stationary and unpredictable noise compared to classical filters
- Outperform conventional methods like Wiener filtering and LMS-based adaptive filters across objective metrics (e.g., SNR, PESQ, STOI)

However, these benefits come with trade-offs, including increased computational complexity, dependence on large labeled datasets, and potential limitations when encountering unseen noise environments.

Overall, deep learning–based adaptive noise cancellation is a powerful and promising solution for enhancing speech signals in challenging low SNR scenarios, with strong potential for real-world applications such as telecommunications, hearing aids, and voice-controlled systems.

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