SIGNAL DISTORTION AND NOISE REDUCTION TECHNIQUES IN ANALOG SYSTEMS

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ABSTRACT

Speech is a signal produced by humans to interact and communicate. Different information is gained from speech signals, such as the language being spoken, emotion, gender, speaker identification, and other information. Speech signals are exposed to different noises, which can be generated at the beginning of the speech or during the transmission. Due to this problem, noise reduction processes are an interesting field in different communication application systems that cultivate the intelligibility and quality of speech signals. It refers to removing or reducing the background noise in order to obtain an improved quality of the original speech signal without distorting the original signal. This paper reviews the state-of-the-art research, reviewing different speech enhancement filters and algorithms and comparing their performance to reach a conclusion about which is the best filter or the most effective one based on the kind of noise that was used and the most difficult noise to remove from the signal. Signal integrity and noise reduction remain central challenges in both analog and digital signal processing. The preservation of signal fidelity during acquisition, transmission, and transformation is vital for high-performance systems in domains such as telecommunications, biomedical instrumentation, and radar systems. This paper presents a comprehensive review and application of advanced techniques that enhance signal integrity and mitigate noise in both the time and frequency domains. Emphasis is placed on adaptive filtering, wavelet-based denoising, spectral shaping, and hybrid approaches that combine deterministic and statistical models.

Keywords: *Signal integrity and noise reduction, analog and digital signal processing, digital signal processing*

INTRODUCTION

Audio noise reduction system is that kind of system which is helpful to remove the unwanted noise from speech signals. Audio noise reduction can be classified into two kinds. Complementary type and Non complementary type. Complementary type involves the compression of audio signal and proper way before recorded. Non Complementary Type (single ended type) is an efficient technique to reduce the noise level which is present in source material already. Both analogue and digital devices have particular quality that make them prone to noise. There is an active noise control (ANC) which is also called noise cancellation or active noise reduction (ANR) is technique for reducing the unnecessary sound and that sound which is not processed, by addition of a second sound, specifically designed to cancel the existing one. sound is an analog signal that works on frequency, which comprises of compression phase and rarefaction phase Noise reduction to recover a target signal from an input waveform is important in a number of fields. We usually use a frequency spectrum to remove noise from the input waveform. Although it is difficult to distinguish a signal from the noise in the time domain, this task tends to become easier in the frequency domain. However, it is difficult to filter out noise that is similar to a signal. For example, the consonant, which is the part of the sound that has a frequency spectrum that is similar to a noise. This study proposes a basic technology by which to remove a noise from musical sound including several periodic signals. We selected white noise and pink noise as the noise signals. These noises are common in cities as well as in nature and have a continuous spectrum. Based on this study, we can remove white noise, including wideband noise such as pulse and white noise, from an old music recording in order to apply digital remastering in multimedia industries. We will also be able to remove noise from a recording of a singing voice because this is a periodic signal. When listening to music in a high-noise environment, difficulty in hearing the music and the presence of ambient noise can decrease the level of enjoyment. Therefore, various noise reduction methods are being investigated, and a number of noise reduction techniques have been proposed. The spectral subtraction method is a widely used approach in which the target signal is extracted from a noisy signal by measuring the noise in advance and modeling the statistical spectral envelope characteristics. The SS method does not require multiple microphones, and highly effective results can be obtained by using a relatively simple algorithm. For this reason, many techniques for improving the SS method have been proposed. Sorensen and Andersen also used the SS method in combination with speech presence detection. Active noise control (ANC) is a method for reducing the unwanted disturbances by the introduction of controllable secondary sources, whose outputs are arranged to interfere destructively with the disturbance from the original primary source. In order to obtain good cancellation, it is generally important that the secondary source is adjusted to compensate for changes in the primary noise source. Noise cancellation in headphones relies on the acoustic isolation characteristic of headphones with active noise reduction by their nature, headphones block out some degree of external noise because the ear-cups absorb it, but active noise control goes a step further and diminish the noise that manages to get through. Active headphones are used mainly in highly noisy environments to protect the user from the excessive noise.

LITERATURE REVIEW

Abhinav Jauhari (2016) Noise is defined as any kind of undesirable disturbance, whether it is borne by electrical, acoustic, vibration, or any other kind of media. Noise consists of unwanted waveforms that can interfere with communication. Noise cancellation is a method to reduce or completely cancel out undesirable sound Noise cancellation tries to 'block' the sound at the source instead of trying to prevent the sounds from entering our ear canals. Noise cancellation technology is aimed at reducing unwanted ambient sound, and is implemented through two different methods. The first of these is passive noise cancellation: an approach that focuses on preventing sound waves from reaching the eardrum, and includes devices such as circumaural headphones or earbuds . The other technique used to achieve the same – and often better – result is active noise cancellation, which uses aural overlap and destructive interference to target and attenuate background noise. While passive and active noise cancellation may be applied separately, they are often combined to attain maximum effectiveness in noise cancellation.

N. Parimon (2015) Over the past few decades, the problem of controlling noise level in the environment especially in the audio processing field has been the focus of a tremendous amount of research. Many papers have dealt with noise reduction in audio applications to improve the quality of audio signals. The purpose of this paper is to study the methods and techniques used for noise reduction in audio applications depending on certain types of scenario and audio signals. The approach of this study also include on improving speech signals in the various speech enhancement methods

Manjeet Singh (2014) Digital filters effectively reduce the unwanted higher or lower order frequency components in a speech signal. In this paper the speech enhancement is performed using different digital filters .In this real noisy environment is taken into consideration in the form of Gaussian noise. The Time domain as well as frequency domain representation of the signal spectra is performed using Fast Fourier transformation technique. MATLAB in built functions are used to carry out the simulation. Gaussian type noise is added using in-built function randn and keyboard noise is added as a second speech file to the original speech signal. The filters remove the lower frequency components of noise and recover the original speech signal. It is also observed that keyboard noise is typical to remove as compared to Gaussian type but these filters performed well to get sharper spectra of original speech signal.

Komal Singla (2014) Speech signal analysis is one of the important areas of research in multimedia applications. Digital filters effectively reduce the unwanted higher or lower order frequency components in a speech signal. The additive noise includes periodical noise, pulse noise, and broadband noise related problems. The noise generated by the engine is one kind of periodical noise while the one generated from explosion, bump, or discharge is pulse. There are many kinds of broadband noise, which may include heat noise, wind noise, quantization noise, and all kinds of random noise such as white noise and pink noise. Statistical relationship between the noise and speech; i.e. uncorrelated or even independent noise, and correlated noise (such as echo and reverberation). In acoustics applications, noise from the surrounding environment severely reduces the quality of speech and audio signals. Therefore, basic linear filters are used to denoise the audio signals and enhance speech and audio signal quality. Our objective is of a noise reduction system with heavily dependent on the specific context and application as to increase the intelligibility or improve the overall speech perception quality which aimed to reduce unwanted ambient sound by implementing through different filters.

Toshio Yoshizawa (2011) The spectrum subtraction method is one of the most common methods by which to remove noise from a spectrum. Like many noise reduction methods, the spectrum subtraction method uses discrete Fourier transform (DFT) for frequency analysis. There is generally a trade-off between frequency and time resolution in DFT. If the frequency resolution is low, then the noise spectrum can overlap with the signal source spectrum, which makes it difficult to extract the latter signal. Similarly, if the time resolution is low, rapid frequency variations cannot be detected. In order to solve this problem, as a frequency analysis method, we have applied non-harmonic analysis (NHA), which has high accuracy for detached frequency components and is only slightly affected by the frame length. Therefore, we examined the effect of the frequency resolution on noise reduction using NHA rather than DFT as the pre-processing step of the noise reduction process. The accuracy in extracting single sinusoidal waves from a noisy environment was first investigated. The accuracy of NHA was found to be higher than the theoretical upper limit of DFT. The effectiveness of NHA and DFT in extracting music from a noisy environment was then investigated.

Noise in Signal Conditioning Circuits

Noise can be separated into two distinct categories, extrinsic (interference) and intrinsic (inherent). Electrical and magnetic noise are forms of extrinsic noise. They can be periodic, intermittent, or random. System designers can reduce their effects in a number of ways. Intrinsic noise can be defined as random processes due to quantum fluctuations inherent in all resistors and semiconductor devices (PN junctions) that create voltages and currents in any application. Noise cannot be completely eliminated. Thermal agitation of electrons and random generation and recombination of electron-hole pairs are examples of inherent noise that IC manufacturers try to reduce with better processes and design techniques. It is very difficult to read values accurately and consistently from the p-p noise graphs. When noise power density is plotted versus frequency, it provides a visual indication of how power is distributed over frequency. The noise spectral density shows the noise energy at a given frequency, while the rms number gives the rms value over a given bandwidth or time interval. It is always good to know the p-p noise value.

Audio Noise

Audio noise reduction system is the system that is used to remove the noise from the audio signals. Audio noise reduction systems can be divided into two basic approaches. The first approach is the complementary type which involves compressing the audio signal in some well-defined manner before it is recorded (primarily on tape). On playback, the subsequent complementary expansion of the audio signal which restores the original dynamic range, at the same time has the effect of pushing the reproduced tape noise (added during recording) farther below the peak signal level—and hopefully below the threshold of hearing. The second approach is the single-ended or non-complementary type which utilizes techniques to reduce the noise level already present in the source material—in essence a playback only noise reduction system. Noise reduction is the process of removing noise from a signal. All recording devices, both analogue or digital, have traits which make them susceptible to noise. Noise can be random or white noise with no coherence, or coherent noise introduced by the device's mechanism or processing algorithms. Their is a Active noise control, also known as noise cancellation, or active noise reduction, is a method for reducing unwanted and unprocessed sound by the addition of a second sound specifically designed to cancel the firs.

Importance of Noise Reduction

Noise reduction is essential to ensure the efficient operation of RF communication systems. By improving the SNR, the system can transmit data more reliably, with fewer errors and less need for retransmissions. In applications like mobile communication, satellite systems, and military-grade communication networks, high signal quality is essential for both security and performance. Without adequate noise reduction, these systems suffer from a range of issues, including communication dropouts, signal distortion, and decreased bandwidth efficiency. This is especially critical in high-frequency RF systems, where the impact of noise becomes more pronounced due to the higher energy of unwanted signals. Consequently, the development of robust noise-reduction techniques is paramount to ensuring reliable, high-quality RF communication.

Noise Reduction Techniques In Digital Circuits

Digital circuits face unique challenges due to switching noise, crosstalk, and quantization errors. Noise immunity is enhanced through techniques like error detection and correction codes, differential signaling in high-speed data transfer, and adaptive clocking mechanisms. Shielding and proper routing reduce interconnect-induced noise, while on-chip decoupling capacitors mitigate power supply noise. Clock gating and spread-spectrum clocking help reduce EMI in high-speed designs. In advanced VLSI, adaptive body biasing and voltage scaling are also employed to balance noise reduction with energy efficiency.

METHODOLOGY

The methodology employed in this study follows a rigorous, step-by-step approach to designing, implementing, and evaluating a finite impulse response (FIR) filter aimed at reducing noise in radio frequency (RF) communication systems. Each phase of the methodology has been carefully developed to ensure that the filter effectively mitigates noise without degrading the quality of the desired signal. This section provides a detailed technical breakdown of the entire process, including signal analysis, filter design, simulation, and performance evaluation Before designing the FIR filter, a thorough analysis of the RF signal and its noise characteristics is required. The first step in this process involves capturing the RF signal that is susceptible to various noise sources. To characterize the noise, we analyze the power spectral density (PSD) of the received signal, using the Welch method for estimation. By calculating the PSD, we identify the frequency bands where noise dominates. Specifically, the presence of thermal noise and adjacent channel interference (ACI) is observed within a bandwidth that extends beyond the desired signal's frequency range. It is observed that this approach prevents both over and under subtraction as well as signal distortion. Furthermore, the estimate of the enhanced output signal is obtained by the inverse fast Fourier transform (IFFT) of the enhanced spectrum using the phase of the original noisy spectrum. The resulting signal is overlap added to reconstitute the enhanced output signal

RESULTS AND DISCUSSIONS

It can be seen from Figure 1 and Table 1 that the noise reduction performance of this method is significantly improved compared with the two traditional methods. The SNR is improved by about 10 dB for signals with an input of −8 dB to 0 dB, and the SNR increases by about 8 dB for signals with an input of 0 dB to 10 dB. The noise reduction performance is also improved compared with the standard GAN when the input signal is more than −2 dB. Compared with the WT and EMD noise reduction methods, the output signal-to-noise ratio is improved by about 4dB under the condition of 0 dB signal-to-noise ratio. This shows that the method has significantly improved the performance of signal noise reduction.

Table 1. Specific data of noise reduction performance comparison of different methods

SNR/dB	Ragan (dB)	GAN (dB)	WT (dB)	EMD (dB)
−8	3.58	3.30	0.83	−0.16
−6	5.01	4.73	2.13	1.46
−4	6.47	6.21	3.55	3.31
−2	8.16	7.85	5.00	4.45

0	10.12	9.64	6.65	6.41
2	11.96	11.33	8.25	6.21
4	13.65	13.01	9.96	8.07
6	15.24	14.58	11.61	10.14
8	16.65	16.08	13.39	12.07
10	17.96	17.38	15.19	13.96

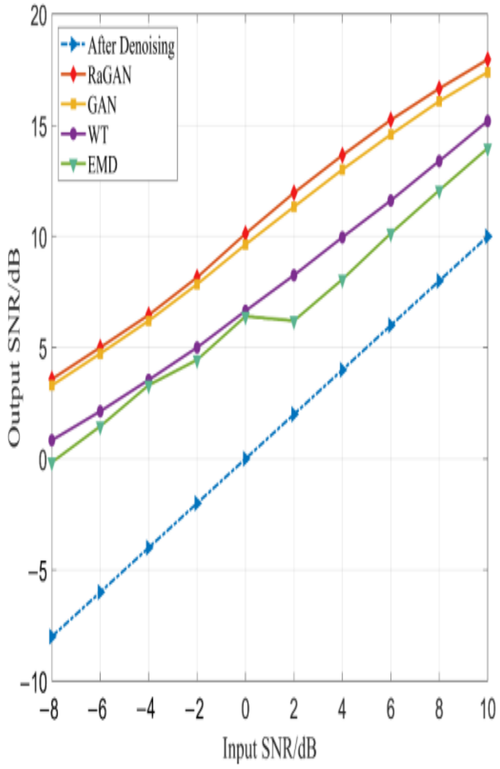

Figure 1. Comparison of noise reduction performance of different methods

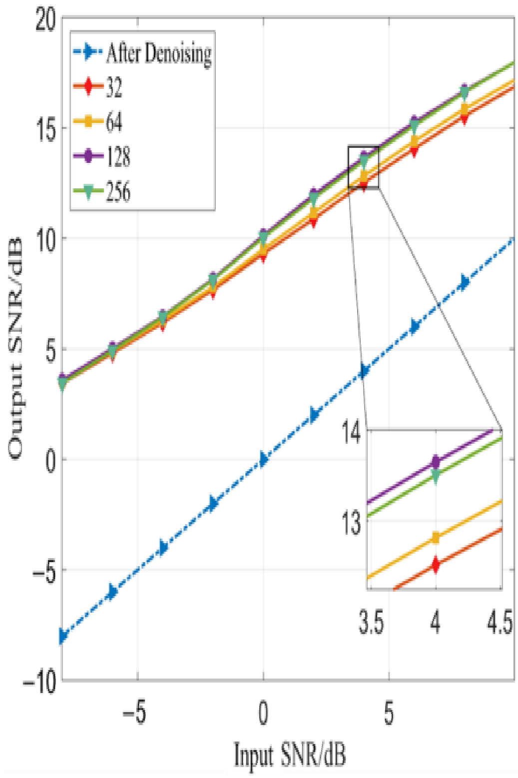

Figure 2. Comparison of noise reduction performance of different number of hidden nodes

It can be seen from Figure 2 that the noise reduction performance of the model is closely related to the number of hidden layer nodes in Bi-LSTM. With the increase in the number of nodes used, the noise reduction performance of the model is also improved. When the number of hidden layer nodes is 128, the noise reduction performance of the model is the highest. However, when the number of hidden layer nodes exceeds 128, due to the large number of model parameters, the performance of the model cannot be improved by increasing the number of nodes.

CONCLUSION

We have proposed a new noise reduction method using linear prediction error filter and adaptive digital filter. From the experimental results, it was observed that there was improvement of SNR in the extracted voice signal, and this proposed noise reduction method is also available under the practical environment. Further researches involve an improvement of the tracking ability to the non-stationary noise like a tunnel noise, a reduction of the residual noise and a performance evaluation in a test product. Also, it prevents signal distortion that is associated with the conventional method and offers comparatively higher signal-to-noise ratio. Therefore, the proposed approach relatively offers positive improvement with no adverse effect on the processed signal. The enhancement in the processed signal is due to the fact that the non-uniform effect of noise on the signal spectrum is taken into consideration over the entire speech spectrum. In this paper a comprehensive analysis of the impact of the use of noise reduction and filtering on the quality of processing noisy audio files was carried out. As part of the research, it was possible to achieve the set goals and solve the set tasks. The noise generated by the engine is one kind of periodical noise while the one generated from explosion, bump, or discharge is pulse noise problem. Butterworth filter, that is used to reduce the noise from the signals with the different frequency and ripple factor.

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