NEUROMORPHIC NOISE ATTENUATION BASED ON PITCH IN HEARING AIDS

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Abstract—The Neuromorphic noise attenuation which is based on the pitch for hearing aids with low computational complexity and hardware complexity has been presented in this paper. The proposed noise reduction algorithm consists of noise attenuator to attenuate the background noise and enhance the speech. Then it has pitch scale harmonic filter (PSHF) to detect the speech by calculating the pitch of the signal. The neuromorphic noise attenuator reduces the noise according to the performance of PSHF Simulation results show that pitch based noise reduction algorithm has very good SNR compared to non-pitch based noise reduction algorithms like mean square error, wiener filter, etc., both in stationary and non-stationary noise environments.

Keywords—Neuromorphic noise attenuator; Hearing aid; Pitch Scaled Harmonic Filter; computational complexity; Noise reduction; Stationary and non-stationary noise.

I. INTRODUCTION

Speech is the most significant mode of human communication. The essential speech communication process includes a talker, who utters a speech sound, and a receiver, who listens to the sound and then decodes the meaning. This process, however, is subject to interference in realistic acoustic environments; the acoustic waveform reaching the listener’s ears is usually composed of sound energy from multiple environmental sources. The interfering sound can be a stationary noise, such as an ambient noise from an air conditioner, or a non-stationary interference, such as door slams, music, and other speech utterances. A rather interesting example occurs at a crowded party, where many people talk simultaneously with a variety of interfering noises in the background.

In hearing aids (HA) systems, signals are enhanced to balance the hearing loss of patients. Conversely, the improved background noise may degrade the speech quality and intelligibility or even spoil the left over hearing capacity of patients. Thus, noise reduction is a key block in hearing aid system applications. The noise reduction algorithms based on one microphone is divided into three types: spectral subtraction algorithm [1], [2], statistical model based algorithm [3], [4] and subspace algorithm [5]. The noise reduction algorithm which depends on the statistical mode can effectively reduce background noise, but the computational complexity is too high to be implemented for HA applications and produce artificial noise problem. Thus, the spectral subtraction algorithm is frequently used in a low power HA hardware implementation. Generally in an HA system VAD is used to differentiate between speech dominated duration and noise dominated duration. The traditional VAD usually detects voice based on energy [6], zero crossing rate [7] or entropy [8]. The computational complexity of these methods is low enough for HA applications and the accuracy is quite high stationary noise environment, but, at non-stationary noise environments, the accuracy is quite low due to inaccurate estimation of background noise. LTVS-VAD [9] uses long-term signal variability measure to separate noise from noisy speech and this characteristic is used as VAD. Due to the computation of the R frames, the computational complexity is very high and the algorithm will exceed the latency tolerance of HA (about 10 ms 15 ms) [10]. Hidden-Markov-model-based (HMM-based) VAD [11] gives very high accuracy even in non-stationary noise environments but the computational complexity is very high because Mel-frequency spectral is required which is very hard to apply in hearing aids applications.

Another method has been developed for hearing aids is uniformly modulated filter bank system for signal analysis and synthesis. In this two stage filter banks are introduced [12], its frequency resolution is good but at the low frequencies SNR is also very low. Therefore, a neuromorphic pitch-based noise reduction algorithm had been proposed [13]. The complexity of the design is calculated by introducing insertion gain (IG) block amplifies the enhanced signal of each sub band individually to compensate the hearing loss of patients in each sub band [14]. To introduce low complexity hardware and less
computational complexity Pitch based filter is introduced [15]. Then perform a filtering in the frequency domain using the short-time Fourier transform in order to separate the harmonic and non-harmonic parts of the processed signal [16]. PSHF has been designed to separate the periodic and aperiodic components of speech signals [17]. Then statistical learning of feature extraction like pitch determination by Nonnegative Matrix Factorization (NMF) and RAPT algorithms [18]. Next to evaluate the experimental results keele pitch reference database had been used [19]. By considering all the results the neuromorphic attenuator cascaded with Pitch Scaled Harmonic Filter (PSHF) to obtain better performance.

The outline of this paper is organized as follows. Section II describes the Neuromorphic attenuator with Pitch Scaled Harmonic Filter (PSHF) and its working process. Section III, describes the evaluation results and performance of objective measures of Pitch based Neuromorphic Attenuator and its SNR. Finally, Section IV the paper is concluded.

II. METHODOLOGY USED

A. Neuromorphic Pitch

Voiced speech signals can be considered as quasi-periodic with Neuromorphic Pitch. The basic period is called the neuromorphic pitch period. The average pitch frequency (in short, the pitch), time pattern, gain, and fluctuation change from one individual speaker to another. For speech signal analysis, and especially for synthesis, being able to identify the Neuromorphic pitch is extremely important. A well-known method for pitch detection is pitch-based voice activity detector (pitch-based VAD).

It is based on the fact that two consecutive cycles have a high cross-correlation value, as opposed to two consecutive speech fractions of Neuromorphic Pitch length but different from the pitch cycle time. This process will be followed on pitch-scaled harmonic filtering (PSHF).

B. Neuromorphic Noise Attenuator

The noise reduction is a key block in hearing aid system applications. In hearing aids (HA) systems, signals are amplified to compensate the hearing loss of patients. However, the improved background noise may corrupt the speech quality and transparency. To avoid background noise amplification, the system has to suppress the background noise and enhance the speech signal. A neuromorphic noise attenuator is used to protect speech and suppress background noise.

The neuromorphic noise attenuator also employs multiplication for time-domain gain smoothing to reduce the artificial noise problem of traditional spectral subtraction algorithm. The pitch scaled harmonic filter (PSHF) is used to compute the pitch of the speech signal. The calculated pitch is cascaded with neuromorphic noise attenuator to enhance the speech.

C. Pitch Scaled Harmonic Filter

The pitch-scaled harmonic filter (PSHF) is a technique for decomposing speech signals into their periodic and aperiodic constituents, during periods of phonation.

![Fig 2. Pitch Scaled Harmonic Filter](image)

The pitch scaled harmonic filter has the following steps:

1. Input noisy signal
2. Applying window function
3. Taking Fourier Transform
4. Compute Noise Spectrum Magnitude

Through manipulation and substitution of equation (2) we obtain the spectral subtraction estimator $\hat{S}(e^{j\omega})$:
\[ \hat{S}(e^{j\omega}) = \left[ X(e^{j\omega}) - \mu(e^{j\omega}) \right] e^{j\theta(e^{j\omega})}. \quad (4) \]

The error that results from this estimator is given by
\[ \varepsilon(e^{j\omega}) = \hat{S}(e^{j\omega}) - S(e^{j\omega}) = N(e^{j\omega}) - \mu(e^{j\omega}) e^{j\theta(e^{j\omega})}. \quad (5) \]

5. Frame Averaging

In efforts to reduce this error local averaging is used because \( \varepsilon(e^{j\omega}) \) is simply the difference between \( N(e^{j\omega}) \) and its mean \( \mu \). Therefore \( |X(e^{j\omega})| \) is replaced with \( \frac{1}{M} \sum_{i=0}^{M-1} |X_i(e^{j\omega})| \) where \( X_i(e^{j\omega}) = \)ith time-windowed transform of x(k).

By substitution in equation (4) we have
\[ \hat{S}_A(e^{j\omega}) = \left[ X(e^{j\omega}) - \mu(e^{j\omega}) \right] e^{j\theta(e^{j\omega})} \quad (6) \]

The spectral error is now approximately
\[ \varepsilon(e^{j\omega}) = \hat{S}_A(e^{j\omega}) - \hat{S}(e^{j\omega}) \equiv \left[ N - \mu \right] \quad (7) \]

where
\[ |N(e^{j\omega})| = \frac{1}{M} \sum_{i=0}^{M-1} |N_i(e^{j\omega})|. \]

Thus, the sample mean of \( |N(e^{j\omega})| \) will converge to \( \mu(e^{j\omega}) \) as a longer average is taken.

It has also been noted that averaging over more than three half-overlapped frames, will weaken intelligibility.

6. Noise Reduction

Noise Reduction is implemented as:
\[ \hat{S}_A(e^{j\omega}) = \left[ \hat{S}_A(e^{j\omega}) \right] \text{for} \left[ \hat{S}_A(e^{j\omega}) \right] \geq \text{max} \left[ N_N(e^{j\omega}) \right] \]
\[ \hat{S}_A(e^{j\omega}) = \left\{ \begin{array}{ll} \min \left[ \hat{S}_A(e^{j\omega}) \right] & \text{for} \left[ \hat{S}_A(e^{j\omega}) \right] < \text{max} \left[ N_N(e^{j\omega}) \right] \\ \end{array} \right. \]
\[ \hat{S}_A(e^{j\omega}) < \text{max} \left[ N_N(e^{j\omega}) \right] \quad (8) \]

where \( N_N(e^{j\omega}) = N - \mu e^{j\theta(e^{j\omega})} \) and \( \text{max} \left[ N_N(e^{j\omega}) \right] \) is maximum value of noise measured during noise activity.

7. Attenuate Signal during Non-Speech Activity

The output of the spectral estimate of Neuromorphic pitch including signal attenuation is given by:
\[ \hat{S}(e^{j\omega}) = \left\{ \begin{array}{ll} \hat{S}(e^{j\omega}) & T \geq -12 dB \\ cX(e^{j\omega}) & T \leq -12 dB \\ \end{array} \right. \]

8. Signal Reconstruction

Firstly the pitch is calculated using PSHF and then it is cascaded with neuromorphic noise attenuator to enhance the speech. The pitch-scaled harmonic filter (PSHF) is a method for dividing speech signals into their periodic and aperiodic components. The periodic component can be used as an estimate of the part of speech, and the aperiodic component can act as an estimate of noise. The calculated pitch from PSHF is then given to the neuromorphic noise attenuator. The PSHF is based on a calculation of harmonics-to-noise ratio. The neuromorphic noise attenuator decodes the speech and noise. Then the noise is suppressed and the speech is enhanced according to the performance of the PSHF. Finally the improved speech is obtained.

III. RESULTS AND DISCUSSION

A. Non-stationary Noise.

To evaluate the performance of the neuromorphic pitch based noise reduction for non-stationary noise, speech database is used and resample. For the objective evaluations, the speech is distinguished by averaging the results. White Gaussian noise or speech-shaped stationary noise is added to these speech signals at 0 dB segmental input SNR to generate noisy speech files.

![Figure 3. Spectrogram and Waveform of non-stationary Noisy Speech.](a) (b)
Figure 4 shows the waveform and spectrogram of the non-stationary neuromorphic attenuated signal. From this figure it is clearly shown that noise is reduced, and the signal is enhanced and even the SNR is also good compared to non-pitch based filters.

**B. Stationary Noise.**

To evaluate the performance of the neuromorphic pitch based noise reduction for stationary noise, speech database is used. For the objective evaluations, the speech is distinguished by averaging the results. Airport noise is added with original speech signal is considered for the evaluation.

Figure 5 shows the waveform and the spectrogram of input noisy signal of stationary noise of airport noise. Figure 5(a) shows the noisy speech signal of stationary noise. Figure 5(b) shows the spectrogram of the noisy speech signal of stationary noise.

The output from the neuromorphic attenuator based on PSHF shows that even for stationary noise the SNR is high and the speech is enhanced and background noise is attenuated. From the results it is observed that for both stationary and non-stationary noise environments the SNR is not varied much and it is high compared to non-pitch based filters.

It is clear from the graph that SNR of Non-Pitch based filters are less compared to Pitch based Neuromorphic attenuator (PSHF). And that the same time in pitch based filters for stationary and non-stationary noise environments the SNR is not varied much.

Figure 6 shows the waveform and spectrogram of the output from the neuromorphic attenuator for stationary (airport) noise. Figure 6(a) clearly shows the signal is almost free from noise and the signal gets enhanced. From figure 6(b) it is inferred that the frequency resolution is high and the SNR gets increased. It is clear that for both stationary and non-stationary noise environments, the SNR is not varied much and it gives better SNR.

**SNR Estimation**

The filters are compared with the performance metrics, SNR and MSE

\[ \text{SNR} = \frac{P_s(\omega)}{P_n(\omega)} \]

Comparing the SNR of different filters with neuromorphic pitch based noise attenuator.

![Fig 7. Comparison Graph for SNR of different filters.](image-url)
C. Subjective Evaluation

Generally noise reduction algorithms which are non pitch based do not achieve the speech intelligibility gain. To evaluate the improvements in signal quality, the pitch based

D. Objective Evaluation

For objective evaluation of the performance of Neuromorphic attenuator with PSHF has been given with stationary (airport noise) and non-stationary (music) noise speech signals are used. It is observed that the background noise is attenuated and original speech signal is enhanced. The objective measure shows that Neuromorphic attenuator with PSHF for stationary (airport noise) and non-stationary (music) noise the SNR is better compared to non-pitch based filters and signal is enhanced by suppressing the background noise.

IV. CONCLUSION

A low computational complexity hardware-oriented neuromorphic pitch based noise reduction algorithm had designed and implemented by using Pitch Scaled Harmonic Filter to improve the frequency resolution and improve the SNR for stationary and non-stationary noise environments. Different approaches had been evaluated for calculating the pitch with less hardware complexity. The backdrop noise is reduced and speech signal is improved by computing the pitch. Then the SNR is compared for different filters. This can be further improved in the performance of noise reduction and SNR improvement by introducing different approaches to calculate the pitch and improving the quality of the pitch for the speech signal.

REFERENCES


[12] Two-Stage Filter-Bank System for Improved Single-Channel Noise Reduction in Hearing Aids Alexander Schasse, Timo Gerkmann, Member, IEEE, Rainer Martin, Fellow, IEEE, Wolfgang Sorgel, Thomas Pilgrim, and Henning Puder, Member, IEEE


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<th>FILTERS</th>
<th>PITCH</th>
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<th>MSE</th>
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