RESEARCH ARTICLE

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Minimize Frequency Overlapping of Auditory Signals using Complementary Comb Filters

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Abstract

Cochlear hearing impairment causes overlapping of auditory speech signals having close frequency contents. Such impairment arises due to the hardening of hearing cells that effects the frequency-splitting ability of inner ear. Person with such disabilities are unable to distinguish between speech signals with high-frequency correlation. This work proposes an implementation of complementary feedforward comb filters to reduce the overlapping of auditory signals. In auditory frequency overlapping, a lower frequency loses their identities due to presence of higher frequencies. Here, two complementary comb filters have been designed to match alternate critical bandwidths of audio signals. Results shown that presenting these alternate frequency bands to human ear in the even-odd index significantly minimizes the frequency overlapping and thereby improves audibility in the hearing impaired.

Keywords: Cochlear hearing impairment, Complementary comb filters, Frequency overlapping.

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Introduction

According to the damaged area in the human ear, the hearing impairments are classified as conductive, cochlear and retro cochlear impairment. When damage occurs in the outer or middle ear they are termed as conductive impairment, in case of damage location as the inner ear i.e., in the cochlea, it's been referred as cochlear impairment.[1] Lastly, retro cochlear impairments deals with damage in the nerve pathways between the ear and the brain. In conductive impairment, a person can hear the sound with a higher loudness level, and hearing discomfort will also increase. Most often, such conductive impairments are cured through medication or surgical treatment.[2]

Any damage to the transduction functioning of the inner ear causes defection in the cochlea, called cochlear hearing impairment. This impairment deals with losses of inner and outer hearing cells. Aging degenerates the auditory system with the solidification of the basilar membrane that losses inner and outer hearing cells from organ of corti. With increasing age, hearing loss becomes mild to severe with degraded speech perception, specifically with sensitivity loss at higher frequencies.[3, 4]

In recent study, for binaural separation of source the direct sound as well as first early reflection information has been used to model the comb filter.[5] A comb filter with constant bandwidths has been used to separate the frequency components. Filtered signals have been presented through dichotic as well diotic presentation however, no significant improvement has been reported.[6] This is mainly due to the constant bands throughout the audio frequency range and non-viability of binaural fusion in case of two non-similar signals.

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To address this issue, we proposed complementary comb filters with critical bandwidths to reduce the overlapping of auditory signals. In auditory frequency overlapping, a lower frequency loses their identities due to the presence of higher frequencies. Here, two complementary comb filters has been designed to match alternate critical bandwidths of audio signals. Results show that presenting these alternate frequency bands to human ear in the even-odd index significantly minimizes the frequency overlapping and thereby improves audibility in hearing impaired.

A further section of paper explores the causes and effects of auditory frequency overlapping on speech perception ability. The implementation of complementary comb filters has been detailed in the third section. The fourth section discusses the observations derived based on the results obtained. At last the outcomes of proposed methodology have been concluded along with scope for extension of work.

Auditory Frequency Overlapping

Exposure to high intensity sound is the major cause for cochlear hearing impairment. Inherited defect leads to hair cells losses as well as severe damage to neurons of auditory system. Difficulty in hearing high frequencies or increased thresholds for lower frequencies can be observed in typical shapes of audiograms.[7] There are different types of cochlear impairment such as severe to moderate bilateral impairment, profound unilateral impairment and highly severe deafness. Other than these issues, cochlear impairments are largely associated with the recruitment of loudness, poor frequency selectivity, and masking in the temporal domain.[8] This paper mainly focuses on identifying the solution for overlapping of auditory signals in the frequency domain.

Frequency selectivity is defined as the capability of the auditory system to distinguish between concurrently presented sinusoidal elements of sound having different frequencies. The lower the frequency selectivity, higher will be the frequency overlapping. In cochlear hearing impaired, signals with close frequency contents undergo overlapping on each other that result in losing their identities. In frequency overlapping, audibility threshold of one signal surge due to presence of other signal. Generally, the high-magnitude frequency element decreases the response to low magnitude elements at adjacent frequencies.[9, 10]

Audibility threshold also increases due to loss of inner hair cells, it's because inner hair cells generate vibrations in basilar membrane which are responsible for proper transduction in auditory system.[11] Similarly, loss of outer hair cells induces poor selectivity and reduces sensitivity in hearing low sound pressure signals. Expansion of tuning curves intensifies frequency overlapping. Any disruption in the nerve pathway between the auditory system and brain can also be a major reason to impact the frequency selectivity of the human ear.

Complementary Comb Filter

A Series of filters with overlaying passbands can be modeled to replicate the functioning of auditory system. The basilar membrane at each location acts as a filter with a particular center frequency. Initially, signal threshold surges with enlargement in the bandwidth of noise. However, later the threshold remains unchanged even if the bandwidth of noise extends further. Such a bandwidth where threshold of signal freeze increases is termed as critical bandwidth. Frequency selectivity can be best way addressed with the concept of critical bandwidth. Throughout the range of audio frequency, critical bandwidths are continuing to reduce with reduction in center frequencies.[12] In cochlear hearing impaired, auditory filter widens because of higher spread of frequency overlapping particularly at higher frequency elements, reducing frequency selectivity.

Frequency overlapping mainly originates through surrounding noise or by the signal itself. In sound signal, vowels first formant overlaps on the second format and on further higher formant because the level of energy in the first formant is higher than other subsequent formants. This first formant also obstructs transitions of other formants, which particularly effects on identification of consonants.[13]

Design of Feedforward Comb Filters

In this work, to overcome the frequency overlapping, we propose a method based on splitting different frequency bands presented to the left and right ear separately. With the objective to sidestep reduced frequency selectivity we have developed a scheme to present alternate bands of frequencies to both the ears. For the same reason, we have designed two comb filters complementary to each other based on critical bandwidths to split the signal's frequency components.

Comb filter has been designed on the basis of feedforward form where the filter is implemented by adding signal with its delayed version.[3] Difference equation for feedforward comb filter is described in Eq. 1 below.

$$y(n) = x(n) + \alpha\, x(n\text{-}k) \tag{1}$$

Here k is measured in sample, representing length of delay, whereas α is scaling factor. Transfer function derived by applying the z-transform to above equation and represented in the below Eq. 2.

$$H(z) = (\alpha + zk)/zk \tag{2}$$

Frequency response of feedforward comb filter contains sequence of equal spaced notches giving the comb appearance. Magnitude response of feedforward comb filter is given in the Eq. 3.

$$|H(ej\Omega)| = \sqrt{(1+\alpha^2) + 2\alpha\cos(\Omega k)'} \tag{3}$$

Here $(1+\alpha^2)$ is constant, while $2\alpha\cos(\Omega k)$ changes periodically. Therefore, the magnitude response of feedforward comb filter shows periodicity in nature.

Table 1: Nine critical bands filter for left ear

Bands	*1*	*3*	*5*	*7*	*9*	*11*	*13*	*15*	*17*
Passband Frequency (kHz)	0.01-0.20	0.30-0.40	0.51-0.63	0.77-0.92	1.08-1.27	1.48-1.72	2.00-2.32	2.70-3.15	3.70-4.40
Centre Frequency (kHz)	0.13	0.35	0.57	0.84	1.17	1.6	2.16	2.92	4.05

Table 2: Nine critical bands filter for right ear

Bands	*2*	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*
Passband Frequency (kHz)	0.20-0.30	0.40-0.51	0.63-0.77	0.92-1.08	1.27-1.48	1.72-2.00	2.32-2.70	3.15-3.70	4.40-5.00
Centre Frequency (kHz)	0.25	0.45	0.70	1.00	1.37	1.86	2.51	3.42	4.70

Pass Bands using Comb Filters

Using two comb filters, 18 bands with critical bandwidths has been obtained, where each one is producing nineteen critical bands, one for left ear and other for the right ear. Table 1 and 2 shows the odd and even bands with their pass band frequency and center frequency (kHz). This covers all 18 critical bandwidths of the auditory filters.

This separation of frequency bands helps in alteration of frequency components energy and thereby helps in reducing the frequency overlapping effect. Narrow bandwidths has been set to increase frequency contrast since larger bandwidths tends to flatten spectra of input sound signal.

Results and Discussion

Comb Filters Response

In the scheme of frequency splitting, two comb filters have been set to produce complementary pass bands, each covering nine pass bands of critical bandwidths. Based on design equations of feedforward comb the magnitude response for each pair has been obtained. This scheme has been designed with MATLAB having toolboxes and blocksets of signal processing, DSP system and audio toolbox. Figure 1 a) shows the magnitude responses of first feedforward comb filter representing odd bands obtained for presenting to the left ear. Similarly Figure 1 b) shows the resultant magnitude response of second feedforward comb filter covering even bands for presenting to the right ear.

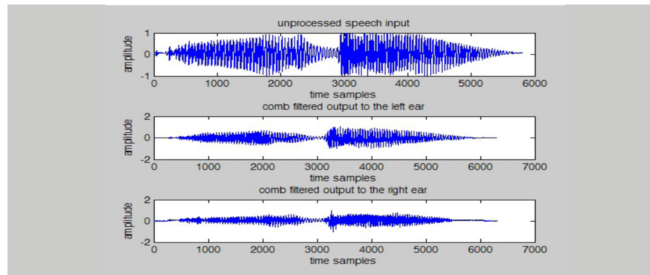

Figure 2: a) unprocessed input speech signal. Filtered output for b) left ear c) right ear

Resultant magnitude responses have shown considerable improvement by lowering frequency distortion with minimized ripples in the pass bands and higher attenuation in the stop bands.

Power Spectrums of Speech Signal

To test the implemented feedforward comb filters, pre-recorded speech signals with VCV context has been used. Figure 2 shows processed outputs for the input speech signal /aza/. This VCV context has been filtered using two complementary feedforward comb filters resulting in two filtered output signals for left and right ear.

Figure 3 shows the power spectrum of processed signals for presenting to the left and right ear. Processed transformation shows a modification in attributes of aural. Transitions of formants and mean power spectrums are the attributes of aural. Purpose of selecting power spectrum

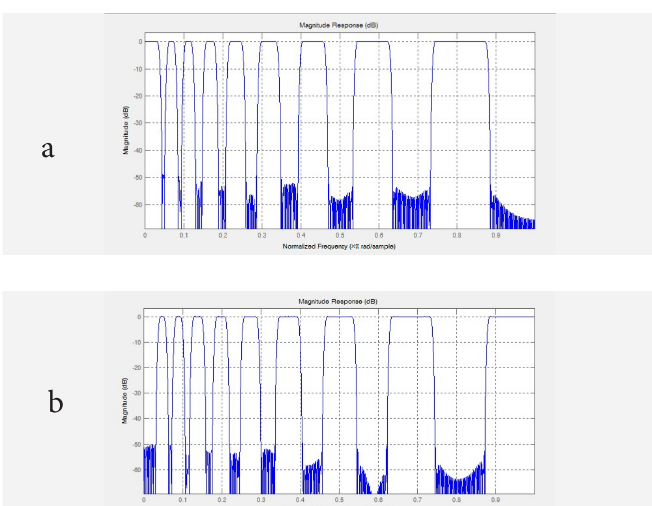

Figure 1: Magnitude responses of feedforward comb filters for a) Left Ear b) Right Ear

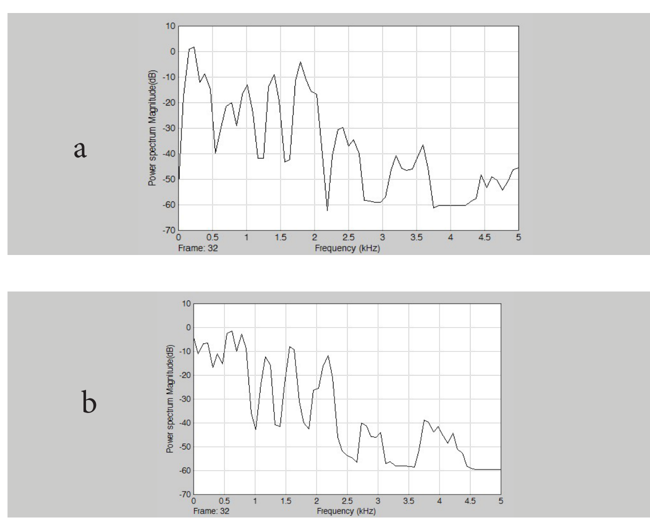

Figure 3: Power spectrum of speech signal. Processed signal for a) left ear b) right ear

as quantifying measure is because power spectrums are enriched with lot of information such as articulation place and high magnitude frequency peaks.

Conclusion

The audibility of cochlear hearing impaired degrades significantly due to higher frequency overlapping. Poor frequency selectivity is the major cause of increased frequency overlapping. To address this issue, we have implemented two complementary feedforward comb filters providing frequency bands that precisely match the critical bandwidths of the auditory system. This pair of filters represent the nine bands in odd-even index manner for simultaneously presenting to the left and right ear. Compared to unprocessed signal, processing methodology reduces perception load and thereby helps in reducing the speech perception time. The power spectrum and magnitude response of processed signals show the scheme's ability to improve the consonantal attributes and frequency selectivity. Overall the proposed methodology remarkably contributes to minimize the frequency of overlapping and plays a major role in enhancing the speech perception for the hearing impaired.

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