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A method of howling detection in presence of speech signal

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ABSTRACT

Hearing aid users suffer from howling sound caused by acoustic coupling between the loudspeaker and the microphone(s) of this device. It is crucial to detect and eliminate the howling before it causes serious irritation to the hearing aid user. This study presents a multiple-feature method which uses voice activity detection (VAD) algorithm to reduce false alarm probability. Experimental results compare the performance of the proposed method with three conventional howling detection techniques in terms of detection probability, false alarm probability, and computational complexity. The proposed method possesses lower false alarm probability and less computational complexity compared to the other methods.

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1. Introduction

The small size of hearing aid devices allows a signal leakage, called acoustic feedback, between the loudspeaker and the microphone(s) [1]. Acoustic feedback can cause severe signal distortions and even an annoying howling sound. The closed-loop system produced by the acoustic feedback can become unstable depending on amplification gain, thereby causing the howling phenomenon which is an oscillation or a resonance with unpleasant sound. Several methods have been proposed to cancel the effects of howling [2–6].

Three main characteristics should be considered in a howling detection algorithm, lack of any of them can make the method unreliable (i.e., it is crucial to detect the howling in its initial stages before its high gain makes it intolerable for the user. It is also important to estimate the howling frequency component correctly. Moreover, the detection algorithm should have low computational complexity).

Howling has been shown to occupy certain time or frequency characteristics which are effective for detection [2,3]. Some howling detection methods compute the power of a frequency component and compare it with any of the following references: a threshold value, the average power of the current frame of the input signal, or the powers of different harmonics of that frequency [2,3]. However, due to some similarities, the howling frequency component cannot be easily recognized from the signal tonal components (e.g. formants in speech, or music tones) [3].

Existing howling detection methods could be classified into two major categories, i.e. frame-based and sample-based methods. Frame-based methods often process the Short Time Fourier Transform (STFT) of the input signal and check some frequency domain properties or temporal features of the howling [3]. Peak-to-Threshold Power Ratio (PTPR), Peak-to-Harmonic Power Ratio (PHPR), Peak-to-Neighboring Power Ratio (PNPR), Interframe Peak Magnitude Persistence (IPMP), and Interframe Magnitude slope Deviation (IMSD) are some known methods in this category [3]. Sample-based methods process the input signal sample by sample in time domain. Teager-Kaiser based method [2,5] and Adaptive Notch Filter (ANF) method [4] are classified in this category. Adaptive non-linear rate-level function which uses the model of auditory system can be also used to reduce the effect of howling [6].

This study proposes a frame-based howling detection approach whose false alarm probability (probability of

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detecting a non-howling component as a howling component) is reduced by applying a voice activity detection (VAD) algorithm in the pre-processing step. In addition to applying the VAD algorithm, some properties of the howling components, i.e. large power, increasing power in the early stages, and negligible harmonic power, are also checked to provide an algorithm with lower false alarm probability. Moreover, as the howling detection procedure does not occur unless an alarm is received from the VAD unit, the computational complexity of the system is low.

Performance of the proposed method is compared with three known howling detection methods. The first one is the single-feature PHPR approach which recognizes a howling sound based on one of the howling main properties, (i.e., not exhibiting significant power at the harmonics and sub-harmonics of the howling frequency). Among the single-feature howling detection algorithms explained in [3], the PHPR approach has previously been shown to achieve good performance. Therefore, PHPR is chosen as a reference method for comparison. The second method is another frame-based method which is a multiple-feature approach proposed by Waterschoot and Moonen [3]. ANF method, a frame-based method, is selected as the third reference approach for comparison. Experimental results show lower false alarm probability and less computational complexity for the proposed method.

The paper is organized as follows. Section 2 explains acoustic feedback and the instability it can cause in the hearing aid. Section 3 presents some conventional howling detection methods. The proposed method and the benefits of using VAD are explained in Section 4. Section 5 compares the computational complexity of the proposed algorithm with the other methods. Sections 6 and 7 present the experimental results and conclusion.

2. Acoustic feedback

Fig. 1 shows a simple diagram for a typical hearing aid. The input signal, $y(n)$, including the desired signal, $s(n)$, and the feedback signal, $\hat{s}(n)$, is collected by the microphone. This signal is amplified by a gain, $G(\omega)$, which is usually a function of frequency and is compatible to the hearing loss level of the patient. The amplified signal, $u(n)$, is fed into the loudspeaker from which the signal leaks back to the microphone as $\hat{s}(n)$. The acoustic feedback path creates a closed-loop structure in Fig. 1. The closed loop system can be written as

$$U(\omega)/S(\omega) = G(\omega)/[1 - G(\omega)F(\omega)] \quad (1)$$

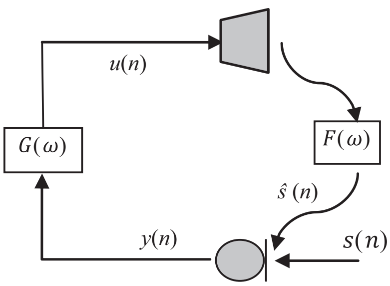

Fig. 1. A simple block diagram of a hearing aid device.

$U(\omega)$ and $S(\omega)$ are Fourier transforms of $u(n)$ and $s(n)$. $G(\omega)$ and $F(\omega)$ are the transfer functions for the forward path (gain of hearing aid) and the acoustic feedback path, where in this paper both are assumed fixed over the algorithm implementation time. According to (1) and the Nyquist instability criterion [7], the system is unstable at frequency f if

$$\begin{cases} |G(\omega)F(\omega)| \geq 1 \\ \measuredangle(G(\omega)F(\omega)) = 2\pi K \end{cases} \quad (2)$$

where, $\omega = 2\pi f/f_s$ and K is an integer. If the unstable system is excited by an input signal which contains a non-zero frequency component at the above frequency, then an oscillation or howling occurs [7].

The howling has an oscillatory/sinusoidal nature, which appears as a large peak in the frequency domain [3]. Using sampling frequency of 16000 Hz, Fig. 2 shows the time domain representation of a speech signal containing the howling and oscillation at frequency of 2100 Hz. The initial stage of the howling is better shown in the lower panel and its frequency can be seen in the next figure.

Fig. 3 is the spectrogram of the previous signal. It shows the frequency domain representations of:

- Some phonemes especially vowels (e.g., around instances 0.2 s and 1.2 s) [8].
- Initial stage of howling (around instance 1.3 s).
- Final stage of howling (howling with a dominant peak around instance 1.5 s).

According to this figure, the formants may be mistakenly detected as the howling frequency because of having large magnitudes. Moreover, waiting to recognize the howling component when its magnitude gets larger than the typical magnitude of formants causes some irritation to the hearing aid users. Therefore, it is essential to recognize these two different components by considering other characteristics of the howling.

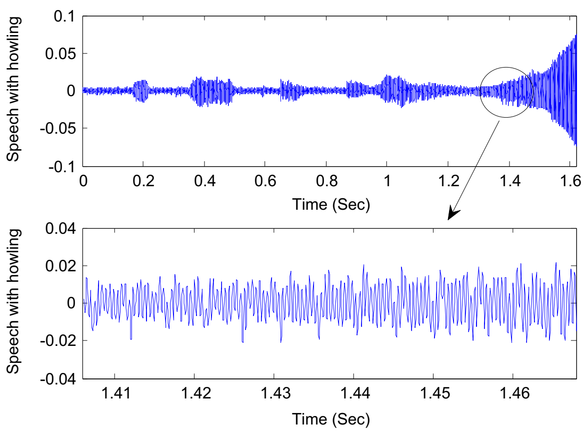

Fig. 2. Upper panel: Speech signal with howling which starts around instance 1.35 s. Lower panel: Early stage of howling.