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A Distance-Based Howling Canceller with Adaptive Bandwidth

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1. Introduction

Public-address system has been widely used in many applications to amplify speech and music signals. In such environments, an acoustic feedback from a loudspeaker to a microphone usually exists and it may causes howling which explosively increases a certain frequency amplitude. The howling is a persistent and an annoying problem in many acoustic enviroments.

To solve this problem, we have previously proposed a howling canceller which uses only distance information between the loudspeaker and the microphone [1] while conventional howling cancellers use a complicated feedback path from the loudspeaker to the microphone [2]–[4]. The howling canceller proposed in [1] is based on a property that a howling frequency depends on the distance between the loudspeaker and the microphone. The discance-based howling canceller repeats the distance measurement and frequency removal to deal with environmental changes. The howling canceller does not require feedback path estimation.

In the distance-based howling canceller, we have utilized a pilot signal for estimating the distance. Using the estimated distance, we compute multiple frequency candidates of the howling, called howling frequencies, and remove them by cascading notch filters that have nulls at the howling frequencies.

We however have a problem about quality degradation of the howling canceller output. In the howling canceller, the notch filters have nulls at howling frequencies estimated from the distance. When the distance becomes long, the width between neighboring nulls of notch filters becomes narrow accordingly. The neighboring bandwidths of notch filters are hence overlapped when the distance is long, and consequently a sound quality of the howling canceller output degrades. In this paper, to solve this problem, we propose an adaptive bandwidth of the notch filter. The adaptive bandwidth narrows when the distance becomes long. We evaluate the speech quality of the howling canceller output with the adaptive bandwidth. We also evaluate its capability of the howling cancellation with the adaptive bandwidth in a practical environment.

2. Conventional distance-based howling canceller

2.1 Condition of howling occurrence

Howling occurs when a phase and an amplitude conditions are satisfied simultaneously. The phase condition is that the frequency phase response of the feedback path is $2\pi l$ ($l = \pm1, \pm2, \dots$), and the amplitude condition is that the frequency amplitude response of the feedback path is greater than 1.

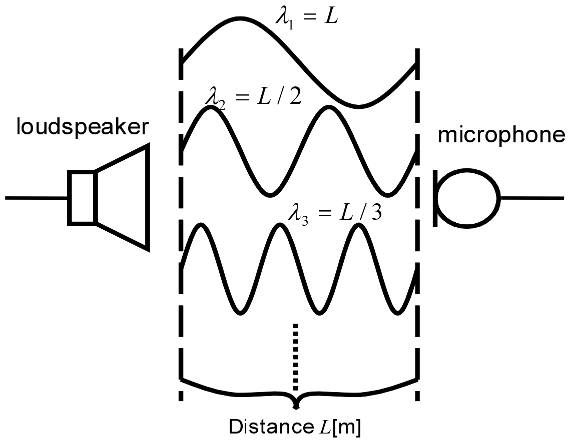


Figure 1. Relation between howling frequency and distance.

Under the assumption that the phase responses of the loudspeaker and the microphone are negligible, the howling frequency depends on only the distance. Fig.1 illustrates the possible wavelengths of the howling, where L is the distance between the loudspeaker and the microphone and the howling wavelength is $\lambda_m, L/m(m{=}1,2,\dots)$. The mth candidate of the howling frequency F_m[Hz] is hence given as

$$F_m = \frac{mc}{L}, \tag{1}$$

where c[m/s] is the sonic speed.

2.2 Distance measurement

To detect the distance, we use a sound arrival time D from the loudspeaker to the microphone. The distance L is given as

$$L = cD. \tag{2}$$

We estimate the arrival time D by using the maximum method [1] as illustrated in Fig.2. In the maximum method, a pilot signal whose frequency is a half of the sampling frequency is transmitted from the loudspeaker to the microphone for a short time. Since the received signal at the microphone includes some disturbances such as a speech or a noise, we employ a HPF (High-Pass Filter) to extract the pilot signal. Taking absolute value of the HPF output, we easily have its

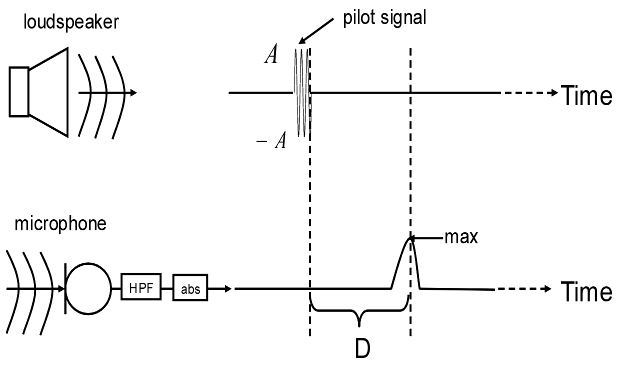


Figure 2. Maximum method

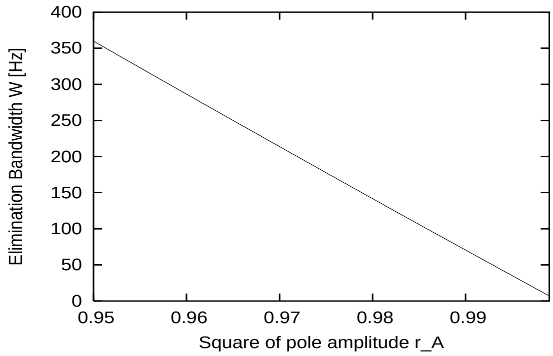


Figure 3. Relation between elimination bandwidth and squared pole amplitude

envelope. The envelope of the HPF output gradually increases during receiving the pilot signal. After the end of receiveing the pilot signal, the envelope gradually decreases. Then we can obtain the arrival time D from the maximum value of the envelope as shown in Fig.2.

2.3 Howling elimination filter

Howling consists of a single sinusoidal noise and hence an ideal howling elimination filter cancels the only certain frequency and gives no influence on other frequency components. Since a notch filter has such a frequency response, we employ it as a howling elimination filter. The frequency response of the notch filter [5] is represented as

$$H(\omega) = \frac{1}{2}\left(1 + \frac{r + ae^{-j\omega} + e^{-2j\omega}}{1 + ae^{-j\omega} + re^{-2j\omega}}\right), \tag{3}$$

where r determines the elimination bandwidth of the notch filter and a determines the elimination normalized radian frequency ω_0 as

$$a = -(1 + r)\cos(2\pi\omega_0). \tag{4}$$

When r approaches to unity, the frequency response gives a more faithful approximation to the ideal frequency response. We put the parameter a to cancel the mth candidate of the howling frequency F_m[Hz] as

$$a = -(1 + r)\cos\left(2\pi\frac{F_m}{F_s}\right), \tag{5}$$

where F_s is a sampling frequency. Since single notch filter removes single howling frequency, we cascade several notch filters for cancelling several candidates of the howling frequency.

3. Adaptive bandwidth

3.1 Principle of adaptive bandwidth

The notch filter nulls of the howling canceller are at howling frequencies calculated from the distance between the loudspeaker and the microphone. When the distance becomes long, the width between neighboring nulls of the notch filters becomes narrow accordingly. The neighboring notch filter bandwidths are hence overlapped when the distance is long, and consequently a sound quality of the howling canceller output degrades.

To solve this problem, we propose an adaptive bandwidth of the notch filter. Firstly, we derive the condition of the elimination bandwidth without the bandwidth overlap. The relation between the elimination bandwidth W[Hz] and the squared pole amplitude r is given as [5]

$$W = \frac{F_s}{2\pi}\cos^{-1}\left(\frac{2r}{1 + r^2}\right). \tag{6}$$

Fig.3 shows the elimination bandwidth W, where we put $F_s = 44.1[kHz]$ and r is set from 0.95 to 0.999. We see from Fig.3 that r and W approximately have the linear relation expressed as

$$W = -7178(r - 1). \tag{7}$$

When the elimination bandwidth W is narrower than the width between the neighboring notch filter nulls, the overlap does not occur. Since the width is $F_1 = c/L$, we have the following bandwidth condition.

$$W \le c/L \tag{8}$$

Substituting Eq.(7) into (8), we have

$$r(L) \ge 1 - \frac{c}{7178L}. \tag{9}$$

Here, we consider a bias frequency caused from a distance estimation error x[m]. We can derive from Eq.(1) the mth bias frequency ΔF_m[Hz] given as

$$\Delta F_m = \left|\frac{mc}{L} - \frac{mc}{L \pm x}\right| = \left|F_m\frac{x}{L \pm x}\right|. \tag{10}$$

Under the assumption $L \gg x$, we approximately have

$$\Delta F_m \simeq \left|F_m\frac{x}{L}\right|. \tag{11}$$

We tolerate the bias frequency ΔF_m, then we have

$$W \geq 2\Delta F_m. \tag{12}$$

Substituting Eqs.(7) and (11) into (12), we have the second pole amplitude condition as

$$r_m(L) \leq 1 - \frac{F_m x}{3589L}. \tag{13}$$

Eq.13 shows that the elimination bandwidth is wider when m is bigger. We can now derive the adaptive elimination bandwidth algorithm as follows:

$$r_m(L) = \begin{cases} r_{bias}, & r_{bias} > r_{min} \\ r_{min}, & \text{otherwise} \end{cases}, \tag{14}$$

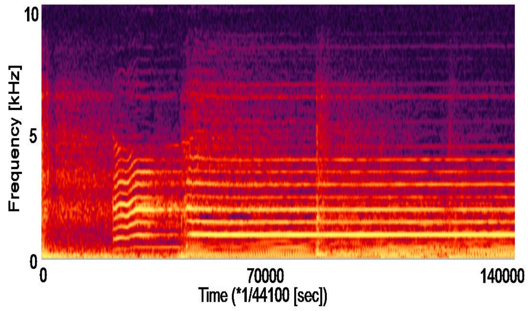
$$r_{min} = 1 - \frac{c}{7178L}, \tag{15}$$

$$r_{bias} = 1 - \frac{F_m x}{3589L}. \tag{16}$$

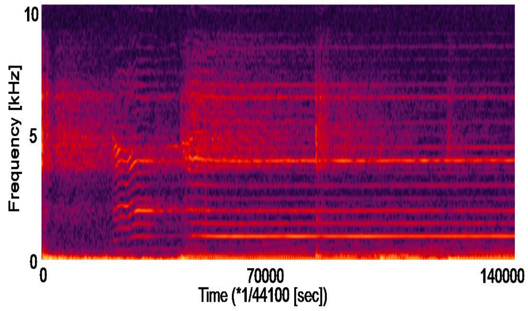
3.2 Simulation

We performed an experiment to evaluate the speech quality of the howling canceller output. We implemented the distance-based howling canceller on the DSK board (mtt:s–BOX)[6] mounting DSP (TI:TMS320C6713)[7]. In the experiment, the condenser microphone (Sony:ECM-23F) and the loudspeaker (ONKYO:GX–77M) were used. We put the sampling frequency F_s=44.1kHz. The sound used in the experiments was a female singing voice, and we set the distance between the loudspeaker and the microphone to 2[m]. We used the proposed adaptive elimination bandwidth which was obtained by substituting $L = 2$, and $x = 0.03$ into Eq.(14) because a maximum bias of estimated distance is 0.03[m][1]. We cascaded 20 notch filters and m is hence from 1 to 20. Fig.4(a) shows the original sound spectrogram. Figs.4(b) and (c) show the howling canceller outputs obtained from the conventional and proposed notch filters, respectively. We see from Fig.4(b) that the conventional notch filters cancelled both the howling candidates and the speech spectra because the elimination bandwidths were overlapped. On the other hand, Fig.4(c) shows that the proposed adaptive filter saved the main speech spectra while eliminating the howling candidates.

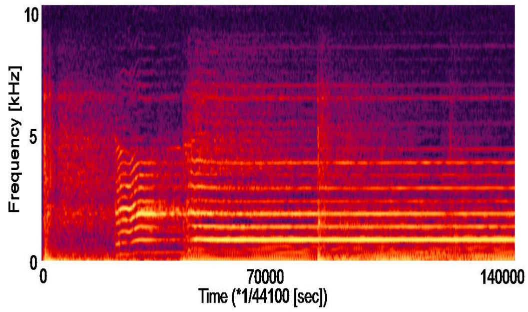
We performed the second experiment to evaluate capability of howling cancellation with the proposed adaptive bandwidth. The procedure of the experiment was as follows: we connected the microphone, the DSP, an amplifier and loudspeaker and gradually amplified the loudspeaker output without the howling canceller. Howling occurs because a thermal noise from the loudspeaker and others are amplified in a closed-loop. We then fixed volume of the amplifier so that the closed-loop gain was 1. We unplugged the microphone from the input terminal and blocked off the closed-loop. In this



(a) Original speech



(b) Conventional constant bandwidth (r=0.95)



(c) Proposed adaptive bandwidth

Figure 4. Spectrograms of the results

condition, we input a white noise into the DSP and measured a power spectrum of the loudspeaker output. Next, we implemented the howling canceller on the DSP and performed the same experiment with the howling canceller and measured the power spectrum of the loudspeaker output. An improvement of howling margin is defined as the difference of the two power spectra. The improvement of howling margin hence directly denotes a sound level enlarged by the howling canceller. Fig.5 shows the improvement of howling margin with a constant bandwidth $r = 0.95$, where the distance L is 2.0[m]. The result shows that we obtained about 2.5dB improvement of howling margin at frequencies not affected by 20 cascaded notch filters. The improvement of howling margin is negative at the howling frequencies. The purpose of howling cancellation is to amplify the volume in voice band (in this paper, the voice band denotes frequencies from 0 to 4000Hz) without howling occurrence. We hence calculated the average improvement of howling margin of Fig.5 in the band. The average is about -14.9dB. We hence see that the frequencies in the voice band are drastically eliminated due to the overlap

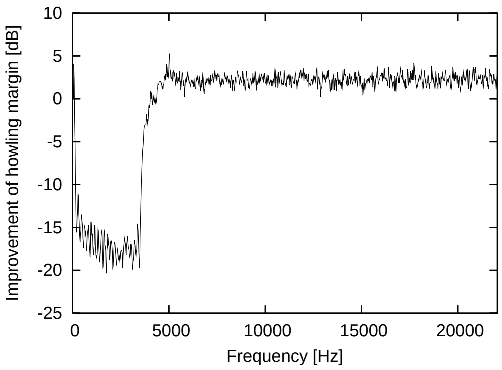


Figure 5. Improvement of howling margin with constant bandwidth

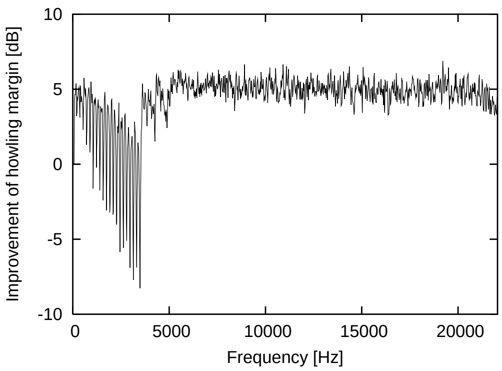


Figure 6. Improvement of howling margin with adaptive bandwidth

of notch filters. Then, we evaluated improvement of howling margin of the howling canceller with the adaptive bandwidth during distance measurement as well. Fig.6 shows the improvement of howling margin with an adaptive bandwidth, where the estimated distance is 2.0[m]. We see from the result that the howling canceller attains 5.0dB improvement of howling margin. The average improvement of howling margin in the voice band is 1.9dB. We see from the result that when *m* is small, the frequencies are saved. When *m* is large, the frequencies are however little eliminated. To recover the eliminated frequencies is our next issue.

4. Conclusion

In this paper, we proposed the adaptive bandwidth of notch filter to solve a problem about the quality degradation of the speech output in the distance-based howling canceller. The proposed adaptive bandwidth of the notch filter can save the main speech spectra while eliminating the howling candidates. We implemented the proposed howling canceller on the DSP and evaluated its cancelling capability in a practical environment. We see from the result that the howling canceller with proposed adaptive bandwidth attains 1.9dB improvement of howling margin in the voice band.

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