PREDICTION-ERROR-METHOD-BASED ADAPTIVE FEEDBACK CANCELLATION IN HEARING AIDS USING PITCH ESTIMATION

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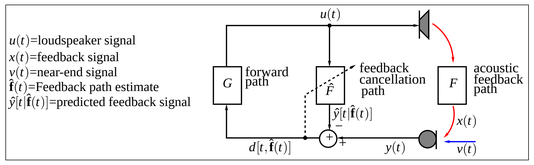
Adaptive Feedback Cancellation (1)

Concept:

- Adaptively model the feedback path and estimate the feedback signal.
- Subtract estimated feedback signal from the microphone signal.



Microphone signal: $y(t) = v(t) + x(t) = v(t) + F(q,t)u(t)$

Feedback-compensated signal: $d(t) = v(t) + [F(q,t) - \hat{F}(q,t)]u(t).$

Problem:

- Standard adaptive filtering results in a biased solution.
- Correlation between near-end signal and loudspeaker signal caused by closed signal loop.

Current solutions:

- Prediction error method (PEM)-based AFC with linear prediction (LP) model [1].
- PEM-based AFC with cascaded near-end signal model [2].

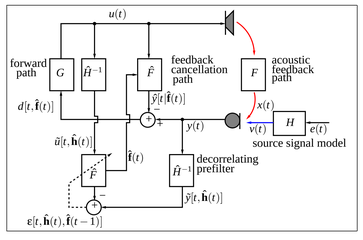
Proposed solution:

- PEM-based AFC with cascaded near-end signal model using pitch estimation [3][4].

Prediction Error Method based AFC (2)

Concept:

- Reduce the correlation between the near-end signal and the loudspeaker signal
- Prefiltering of loudspeaker and microphone signals with inverse near-end signal model



- Single all-pole model (Short-term predictor) fails to remove the periodicity
- A cascade of near-end signal models removes the coloring and periodicity
- PEM delivers an unbiased estimate of the feedback path coefficient vector $\mathbf{f}(t)$

Cascaded near-end signal model: $H_1(q,t)H_2(q,t) = \dfrac{B(q,t)}{A(q,t)}\dfrac{1}{C(q,t)}$

Minimize prediction error: $\min\limits_{\mathbf{f}(t)} \sum\limits_{k=1}^{t} \varepsilon^2(k)$

Prediction error: $\varepsilon[t, \boldsymbol{\xi}(t)] = H_1^{-1}(q,t)H_2^{-1}(q,t)[y(t) - F(q,t)u(t)]$

Near-End Signal Model (3)

Harmonic sinusoidal near-end signal model:

Near-end signal: $v(t) = \sum\limits_{n=1}^{P} a_n \cos(n\omega_0 t + \phi_n) + r(t)$

- ω_0 is the fundamental frequency, a_n the amplitude, and ϕ_n the phase
- $r(t)$ is the noise which is assumed to be autoregressive (AR)
- $r(t) = \frac{1}{C(q,t)}e(n)$ with $C(q,t) = 1 + \sum_{i=1}^{n_C} c^{(i)}(t)q^{-i}$

Near-end signal model parameter estimation:

Fundamental frequency: $\hat{\omega}_0 = \arg\max_{\omega_0} \mathrm{E}\{|\mathbf{h}^H \tilde{\mathbf{d}}(t)|^2\}$

- where $\mathbf{h}$ is the optimal filter.

Amplitude: $\hat{\mathbf{a}} = \left(\mathbf{Z}^H\mathbf{Z}\right)^{-1}\mathbf{Z}^H\mathbf{d}$

- where $\mathbf{Z}$ is the Vandermonde matrix containing the sinusoids

Order: $\hat{P} = \arg\min\limits_{P} M \log \hat{\sigma}_P^2 + P \log M + \dfrac{3}{2}\log M$

- The AR parameters of the noise component $r(t)$ can be estimated using LP

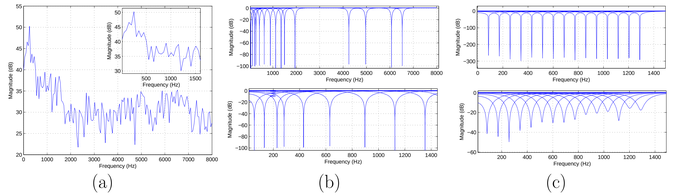
Prediction Error Filter (4)

PEF for sinusoidal components:

- A sum of P sinusoids can be described using an all-pole model of order $2P$
- When noise is added a pole-zero model of order $2P$ should be used

Cascade of second-order sections: $H_1^{-1}(q,t) = \prod\limits_{n=1}^{P} \dfrac{1 - 2\nu_n \cos n\omega_0 z^{-1} + \nu_n^2 z^{-2}}{1 - 2\rho_n \cos n\omega_0 z^{-1} + \rho_n^2 z^{-2}}$ (1)

- The poles and zeros are on the same radial lines
- the poles are positioned between the zeros and the unit circle, i.e., $0 \ll \rho_n < \nu_n \leq 1$.



(a) (b) (c)

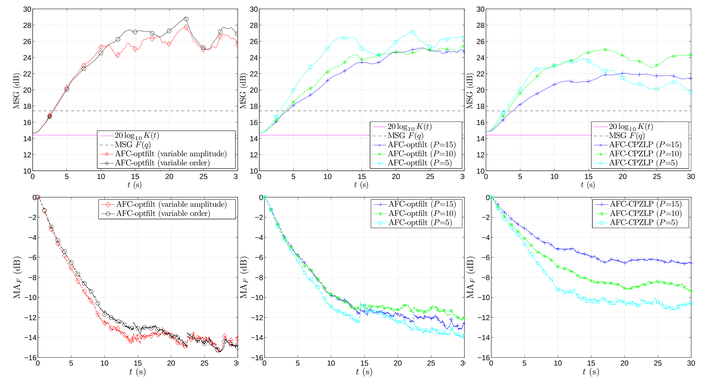
- (a) Speech spectrum used to estimate the PEF
- (b) PEF using CPZLP with $\nu_n = 1$ and $\rho_n = 0.95$ (infinite notch depth)
- (c) PEF using optimal filtering and amplitude

Experimental Results (5)

Performance measures:

Maximum Stable Gain: $\mathrm{MSG}(t) = -20\log_{10}\left[\max\limits_{\omega\in\mathcal{P}} |J(\omega,t)[F(\omega,t) - \hat{F}(\omega,t)]|\right]$

Misadjustment: $\mathrm{MA}_F = 20\log_{10}\dfrac{||\hat{\mathbf{f}}(t) - \mathbf{f}||_2}{||\mathbf{f}||_2}.$



Conclusion (6)

- Hearing aids typically used a linear prediction model in PEM-based AFC
- A harmonic sinusoidal near-end signal model is introduced here in PEM-based AFC
- Performance of a PEM-based AFC with cascaded near-end signal models can be further improved by using pitch estimation methods
- Including variable amplitude and order in the PEF increases the performance
- Overall the achievable amplification in terms of MSG is higher and the misadjustment is lower using a harmonic sinusoidal near-end signal model

References

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