Residual Echo PSD Estimation Based on an Optimal Smoothed System Misalignment for Acoustic Echo Cancellation

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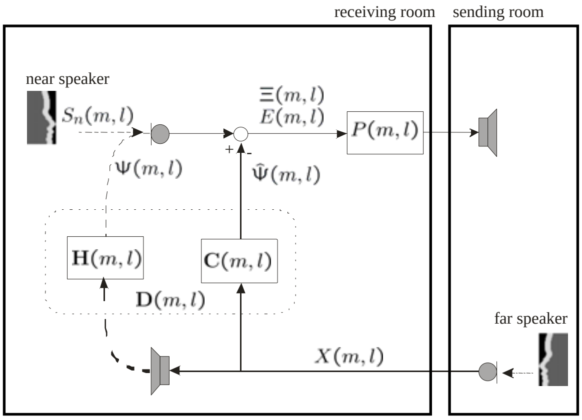
Motivation

- Post-Filtering is a common enhancement technique for the conventional acoustic echo canceller (AEC), especially, when it is diverged or too short.
- A reliable estimate of the (residual) echo power spectral density (PSD) is essential for designing the Post-Filter.
- For short DFT-lengths resulting in low latency a partitioned calculation is necessary, which leads to biased estimates. This bias has to be corrected.

System model

Partitioned frequency domain system model of an acoustic echo canceller in front of a Post-Filter:



$$\begin{aligned}
\mathbf{X}(m,l) &= [X(m,l) \ldots X(m,l-L'_H+1)]^T \\
\mathbf{H}(m,l) &= [H_0(m,l) \ldots H_{L'_H-1}(m,l)]^T \\
\mathbf{C}(m,l) &= [C_0(m,l) \ldots C_{L'_{\mathrm{AEC}}-1}(m,l) \quad 0 \ldots 0]^T \\
\mathbf{D}(m,l) &= \mathbf{H}(m,l) - \mathbf{C}(m,l)
\end{aligned}$$

m : discrete frequency index; $L_{\mathrm{AEC}} = L'_{\mathrm{AEC}} \cdot L_{\mathrm{DFT}}$: length of AEC

l : discrete block index; $L_{\mathrm{H}} = L'_{\mathrm{H}} \cdot L_{\mathrm{DFT}}$: length of room impulse response

Design of the Post-Filter

Spectral subtraction: $$P(m,l) = \frac{\hat{\Phi}_{EE}(m,l) - \hat{\Phi}_{\Xi\Xi}(m,l)}{\hat{\Phi}_{EE}(m,l)}$$

Calculation of the residual echo: $\hat{\Xi}(m,l) = \hat{\mathbf{D}}^T(m,l) \cdot \mathbf{X}(m,l)$

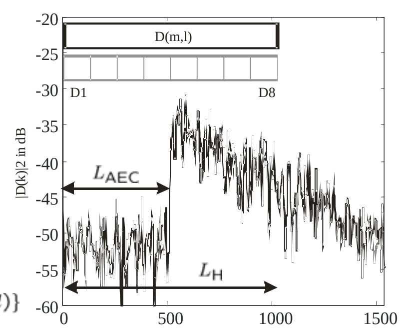
Est. of the system misalignment: $\hat{\mathbf{D}}(m,l) = \mathbf{R}_{XX}^{-1}(m,l) \cdot \hat{\mathbf{\Phi}}_{XE}(m,l)$

Partitioned Calculation of the System Misalignment (I)

Assuming temporarily low correlated loudspeaker signals in the DFT-domain, $\mathsf{E}\{X^*(m,l-i)X(m,l-k)\} \approx 0$, $\forall\, i \neq k$, the partitions of the system misalignment can be calculated independently:

$$D_i(m,l) = \frac{\Phi_{i,X\Xi}(m,l)}{\Phi_{XX}(m,l-i)}$$

$$\Phi_{i,X\Xi}(m,l) = \mathsf{E}\{X^*(m,l-i)\Xi(m,l)\}$$



Partitioned Calculation of the System Misalignment (II)

With $\Xi(m,l) = \sum_{i=0}^{L'_H-1} D_i(m,l) \cdot X(m,l-i)$ the first partition can be rewritten exemplarily:

$$\begin{aligned}
\frac{\Phi_{0,X\Xi}(m,l)}{\Phi_{XX}(m,l)} &= \frac{\mathsf{E}\left\{X^*(m,l) \cdot \sum_{i=0}^{L'_H-1} D_i(m,l) \cdot X(m,l-i)\right\}}{\mathsf{E}\{X^*(m,l) \cdot X(m,l)\}} \\
&= \underbrace{D_0(m,l)}_{\text{true value}} + \underbrace{\frac{\sum_{i=1}^{L'_H-1} D_i(m,l) \cdot \mathsf{E}\{X^*(m,l) \cdot X(m,l-i)\}}{\mathsf{E}\{X^*(m,l) \cdot X(m,l)\}}}_{\text{bias}}
\end{aligned}$$

After substituting the expectation operators $\mathsf{E}\{\cdot\}$ by estimation methods $\hat{\mathsf{E}}\{\cdot\}$ in practical realizations, the bias is nonzero.

Optimal Smoothing of the System Misalignment

A first order recursive smoothing of the system misalignment can be exploited especially with nonstationary signals:

$$\left|\bar{D}_0(m,l)\right|^2 = \alpha \left|\bar{D}_0(m,l-1)\right|^2 + (1-\alpha) \left|\frac{\hat{\Phi}_{0,X\Xi}(m,l)}{\hat{\Phi}_{XX}(m,l)}\right|^2$$

An optimal smoothing factor for the mean of a stochastic system $\bar{D}_0(m,l)$ is obtained by minimizing

$$\left(\left|\bar{D}_0(m,l)\right|^2 - \mathsf{E}\left\{\left|\bar{D}_0(m,l)\right|^2\right\}\right)^2 \stackrel{!}{=} \min_{\alpha}.$$

$$\alpha_{opt}(m,l) = \frac{1}{1 + \frac{\left|\mathsf{E}\left\{|\bar{D}_0(m,l)|^2\right\} - |\bar{D}_0(m,l-1)|^2\right| \Phi_{XX}(m,l)}{\sum_{i=1}^{L'_D-1} \mathsf{E}\left\{|D_i(m,l)|^2\right\} \Phi_{XX}(m,l-i)}}$$

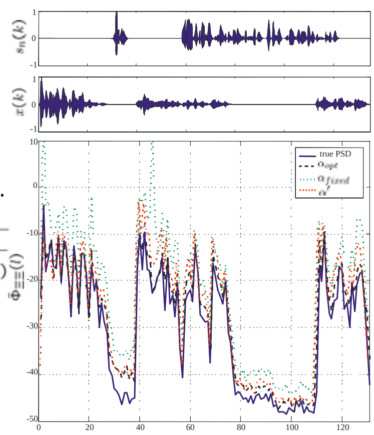
Practical Realization and Simulation Results

- The factor $\left|\mathsf{E}\left\{\left|\bar{D}_0(m,l)\right|^2\right\} - \left|\bar{D}_0(m,l-1)\right|^2\right|$ can be interpreted as a permitted adaptation speed and set constant.
- Typical values for $\tilde{C}$ are in the range of 0.08<$\tilde{C}$<0.12 and thus we choose $\tilde{C}$=0.1.
- As a simplification the dependence on the system misalignment can be neglected.

$$\alpha'(m,l) = \frac{1}{1 + C' \frac{\hat{\Phi}_{XX}(m,l)}{\sum_{i=1}^{L'_D-1} \hat{\Phi}_{XX}(m,l-i)}}$$

- Fixed Alpha as reference

$$\alpha_{fixed} = e^{-\frac{F_B}{\tau \cdot f_s}}$$



Conclusions

- A frequency dependent first order recursive smoothing factor was presented which is robust and straight forward to implement
- Drastical enhancement of the system identification by Wiener-Hopf-Equation
- Reliable redundancy for AEC