An Integrated Approach to Hearing Aid Algorithm Design for Enhancement of Audibility, Intelligibility and Comfort

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Introduction

Hearing Aid Algorithm Goals

- **Audibility**: maximize normal loudness restoration
- **Intelligibility**: maximize signal-to-noise ratio
- **Comfort**: minimize perceptual distortion

Signal Processing Goal

- Integrated approach to gain control algorithm

Processing model

- Analyze received signal into time-frequency grid

$$X(t,f) = S(t,f) + N(t,f)$$

- Process signal by adaptive (real) gain

$$Y(t,f) = G(t,f)\,X(t,f)$$

Prior Art

- Bottom-up approach: ad hoc network of gain modules (for, e.g., noise reduction, compression, de-reverberation, feedback suppression etc.)

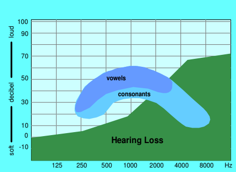
Problem

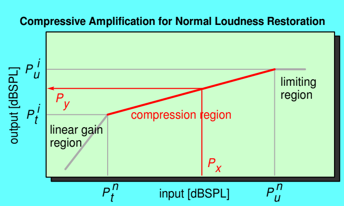
- Signal distortion vs. residual noise trade-off is uncontrolled
- Hearing aids patients are not satisfied (20% of patients do not wear their hearing aids)

'Normal Loudness' Restoration

Problem

- Increased hearing threshold leads to dynamic range reduction and loudness distortion





Restore relative loudness to normal

$$C(G_{lr}) = \left[\frac{(G_{lr}+P_x)-P_t^i}{P_u^i-P_t^i} - \frac{P_x-P_t^n}{P_u^n-P_t^n}\right]^2$$

(where G,P in *log*-domain)

leads to $\boxed{G_{lr} = \alpha\left(\frac{P_t^n}{P_x}\right)^{\beta/2}}$ where $\alpha \equiv \sqrt{\frac{P_t^i}{P_t^n}}$, $\beta \equiv {}^{P_u^i/P_t^i}\log\frac{P_u^n P_t^i}{P_u^i P_t^n}$

- G_{lr} implements compressive amplification

Improving Signal-to-Noise Ratio

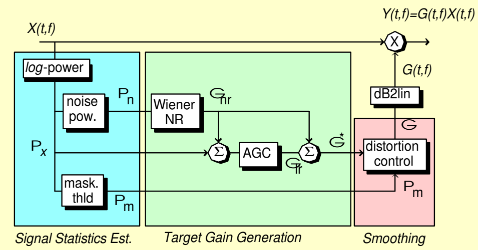
- Estimate 1 (global) *SNR*(*t*,*f*), where *S* refers to target signal (usually speech) and *N* integrates (power of) everything else, including all sources of noise, feedback and reverberation.

- Compute a (motivated) gain, e.g., *Wiener* gain

$$\boxed{G_{nr} = \frac{P_s}{P_s+\hat{P}_n} = 1 - \frac{\hat{P}_n}{P_x}} \quad \text{if } s,n \text{ uncorrelated}$$

Integration and Comfort

- **Cost integration**: loudness restoration of "cleaned-up" signal (target gain *G**), subject to "principle of least processing"



$$\text{target gain } G^* = \alpha\left(\frac{P_t^n}{G_{nr}^2 P_x}\right)^{\beta/2} \times G_{nr} = G_{lr}G_{nr}^{1-\beta} > G_{lr}G_{nr}$$

- **Principle of least processing** (Wolfe, ICASSP 2003)

$$C(G) = \left[GX - \left(1-\frac{P_m}{P_x}\right)S - \frac{P_m}{P_x}X\right]^2 \Rightarrow G = \left(1-\frac{P_m}{P_x}\right)G^* + \frac{P_m}{P_x}\cdot 1$$

Total Integrated Gain

$$\boxed{G = \frac{P_m}{P_x} + \alpha\left(1-\frac{P_m}{P_x}\right)\left(1-\frac{P_n}{P_x}\right)^{1-\beta}\left(\frac{P_t^n}{P_x}\right)^{\beta/2}}$$

- Needs relative power estimates $\hat{P}_m/P_x$, $\hat{P}_n/P_x$, (P_t^n/P_x) and patient signature (α, β)

- to do: formal listening tests

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