Using A-weighting for Psychoacoustic Active Noise Control

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Introduction

Problem

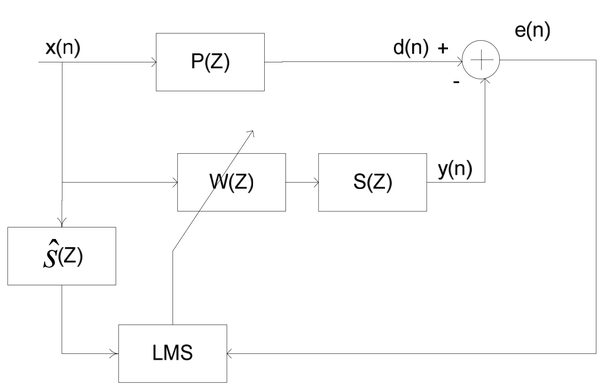
Conventional adaptive active noise control (ANC) aims to attenuate the acoustic noise over the entire frequency band. However, human hearing system has selective sensitivity for different frequency bands. Normal ANC method thus may not perform well in term of human perception.

Motivation

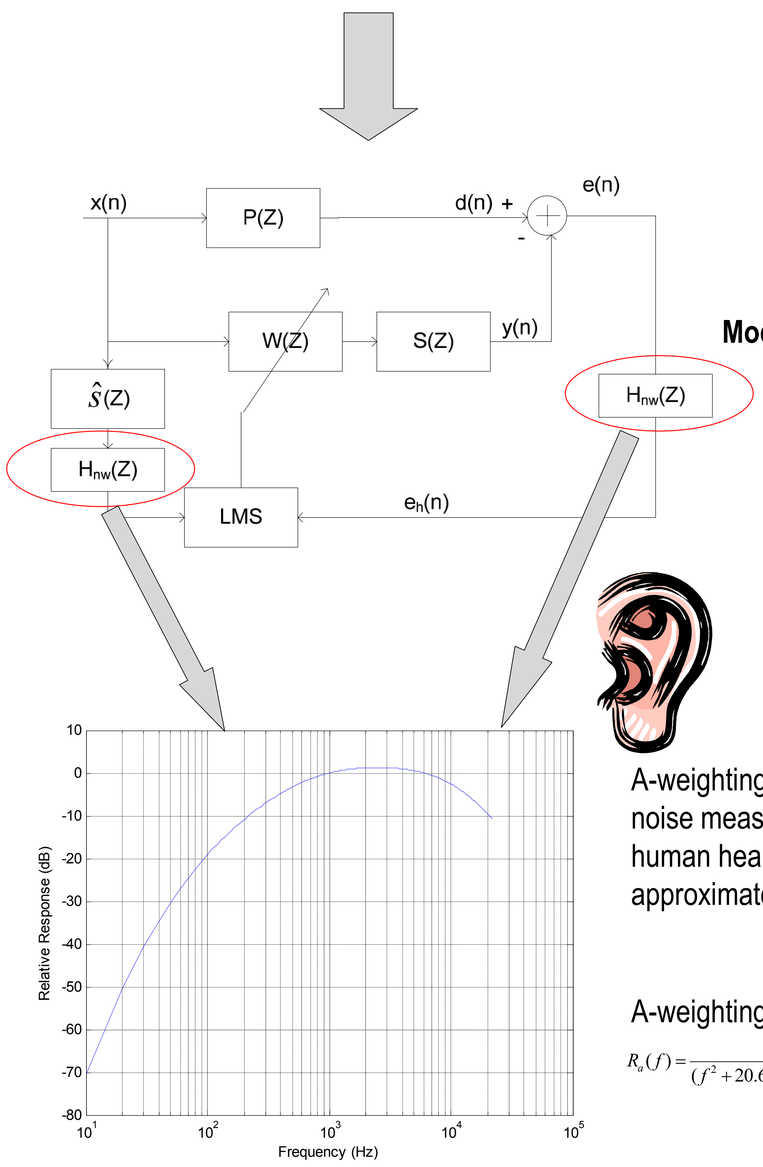
- Conventional ANC system structure should be modified to shape the spectrum of residual noise
- Human hearing characteristics should be included in the new ANC system
- Psychoacoustic measure should be used as performance evaluation criterion to reflect how human ear perceives

Methods

- **Conventional ANC uses filtered-X LMS(FXLMS) structure**
- **Modified ANC uses filtered-Error LMS (FELMS) structure**



Conventional ANC system



Modified ANC system

A-weighting, commonly used in noise measurement, reflects human hearing response approximately.

A-weighting calculation:

$$R_a(f) = \frac{12200^2 \cdot f^4}{(f^2+20.6^2)(f^2+12200^2)(f^2+107.7^2)^{0.5}(f^2+737.9^2)^{0.5}}$$

$$A = 2.0 + 20\log(R_a(f))$$

Performance Evaluation

SPL *vs* Loudness

Conventionally, sound pressure level (SPL) is adopted to evaluate the noise attenuation. SPL belongs to mean square error (MSE) criterion. It treats the entire frequency band indiscriminately regardless of human hearing property.
Loudness, originated from listening experiments, aims to measure the subjective perception of sound by objective method.
Therefore, loudness is more appropriate for performance evaluation since the ultimate goal of ANC is to minimize the effects of acoustic noise on human hearing system.

Loudness calculation:

$$N' = 0.08\left(\frac{E_{TQ}}{E_0}\right)^{0.23}\left[\left(0.5+0.5\frac{E}{E_{TQ}}\right)^{0.23}-1\right]\frac{sone_G}{Bark}$$

$$L = \int_0^{24\,Bark} N' dz$$

E_{TQ}: excitation at threshold in quiet
E_0: excitation that corresponds to reference intensity
N': specific loudness
L: loudness

Results

Three types of noise signals are tested with proposed ANC system

e1(n), e2(n) are residual noise of conventional and modified ANC system, respectively

Multi-tone noise signal:

	SPL(dB) Beginning	SPL (dB) End	Loudness(sone) Beginning	Loudness(sone) End
$e_1(n)$	91.5171	74.0865	34.0300	1.2710
$e_2(n)$	91.5171	73.7746	34.0300	1.9480

Loudness improvement:

34.75%

Mixture of multi-tone noise signal and white noise (SNR = 10dB):

	SPL(dB) Beginning	SPL (dB) End	Loudness(sone) Beginning	Loudness(sone) End
$e_1(n)$	89.8202	75.5871	36.2300	10.4080
$e_2(n)$	89.8202	74.9695	36.2300	11.9540

10.45%

Realistic noise: factory background noise

	SPL(dB) Beginning	SPL (dB) End	Loudness(sone) Beginning	Loudness(sone) End
$e_1(n)$	58.9349	45.8672	4.3110	1.2110
$e_2(n)$	58.9349	45.8695	4.3110	1.2530

3.35%

Conclusion

The key idea stems from the fact that human hearing has frequency selective sensitivity. The modified ANC system features residual noise shaping. A-weighting is incorporated to approximately reflect psychoacoustic property of human ear. Loudness is adopted as performance criterion. Simulations of three types of signals verify the effectiveness of the new system.