KATHOLIEKE UNIVERSITEIT LEUVEN

AES 126th Convention

Comparative evaluation of howling detection criteria in notch-filter-based howling suppression

Toon van Waterschoot
Marc Moonen

K.U.Leuven ESAT-SCD, Leuven, Belgium





Outline

- Introduction:
  - the acoustic feedback problem
  - state of the art in acoustic feedback control
  - research objectives
- Notch-filter-based howling suppression (NHS)
  - howling detection
  - notch filter design
- Howling detection
  - formal problem definition
  - signal features for howling detection
  - single-feature howling detection criteria
  - multiple-feature howling detection criteria
  - NHS simulation results
- Conclusion



Introduction: the acoustic feedback problem



- performance limitation due to acoustic feedback:
  - limited achievable amplification (maximum stable gain)
  - poor sound quality (ringing, howling, reverberation)
  - lack of reliability
- common applications:
  - public address/sound reinforcement systems
  - hands-free communications systems
  - hearing aids

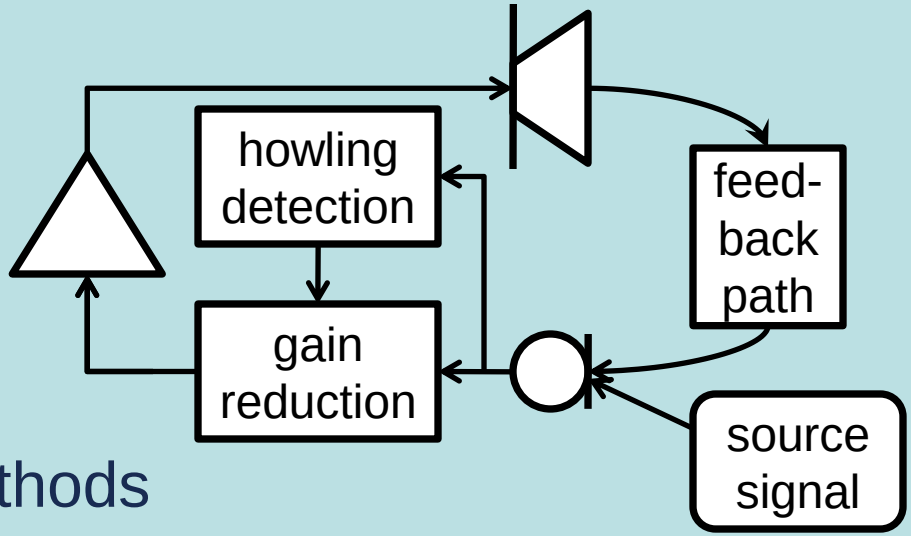


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Introduction: state of the art in acoustic feedback control

Classification of state-of-the-art acoustic feedback control methods:
[van Waterschoot and Moonen, "50 years of acoustic feedback control: state-of-the-art and future challenges", submitted for publication in *Proc. IEEE*, Feb. 2009]



- phase modulation (PM) methods
  - smoothing of "loop gain" (= closed-loop magnitude response)
  - phase/frequency/delay modulation, frequency shifting
- gain reduction methods
  - (frequency-dependent) gain reduction after howling detection
- spatial filtering methods
  - (adaptive) microphone beamforming for reducing direct coupling
- room modeling methods
  - adaptive feedback cancellation (AFC), adaptive inverse filtering



Introduction: research objectives

- gain reduction methods:
  - most widespread feedback control solution in PA/SR applications
  - automation of the actions a human operator would undertake
- classification of gain reduction methods:
  - automatic gain control (full-band gain reduction)
  - automatic equalization (1/3 octave bandstop filters)
  - notch-filter-based howling suppression (1/10-1/60 octave filters)
- observations:
  - notch filter design: based on well-established filter design theory
  - howling detection: little agreement and few experimental results
- research objectives:
  - evaluate existing howling detection criteria in objective way
  - propose novel howling detection criteria (particularly suited for audio signals)



Outline

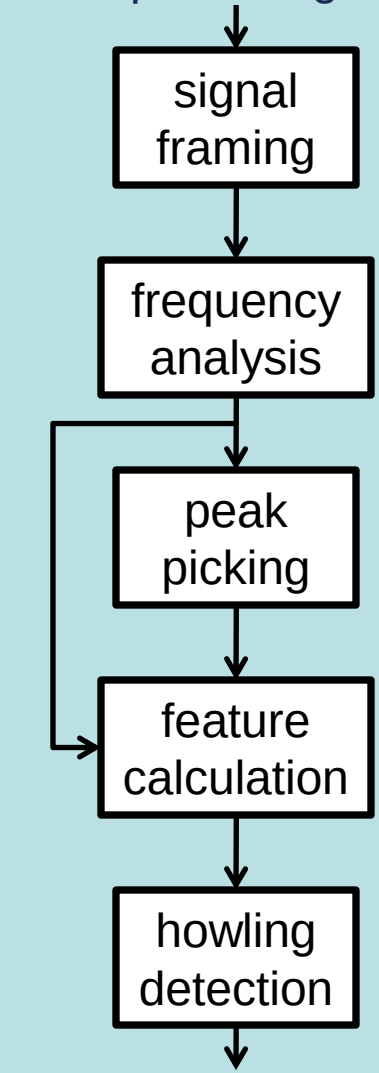
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NHS: howling detection

Note: there are lots of variations on this scheme, however, the basic structure is usually like this

microphone signal $y(t)$



set of notch filter design parameters $\mathcal{D}_H(t)$

divide microphone signal in overlapping frames

$$\mathbf{y}(t) = [y(t+P-M) \ \ldots \ y(t+P-1)]^T$$

estimate the microphone signal spectrum (e.g., DFT-based)

$$\mathbf{Y}(t) = [Y(\omega_0, t) \ \ldots \ Y(\omega_{M-1}, t)]^T$$

select a number *N* of candidate howling components

$$\mathcal{D}_{\breve{\omega}}(t) = \{\breve{\omega}_i\}_{i=1}^{N}$$

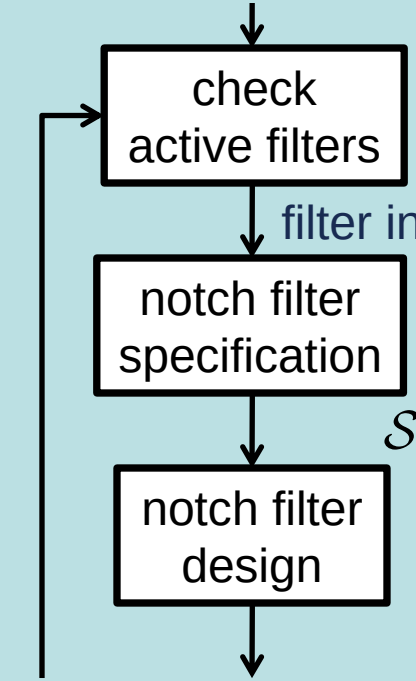
calculate a set of discriminating signal features

perform howling detection & determine design parameters



NHS: notch filter design

set of notch filter design parameters $\mathcal{D}_H(t)$



is a notch filter already active around howling frequency?

no? new filter: center frequency = howling frequency

yes? active filter: decrease notch gain

$$\mathcal{S}_{H_l}(t) = \{\omega_{c,l}, B_l, G_{c,l}\}$$

translate filter specifications into filter coefficients

bank of notch filters transfer function $H(q,t) = \prod_{l=1}^{n_H/2} H_l(q,t)$

- biquadratic notch filter design:
  - analog design + bilinear transform
  - digital design using pole-zero placement

[van Waterschoot and Moonen, "A pole-zero placement technique for designing second-order IIR parametric equalizer filters", *IEEE Trans. Audio Speech Lang. Process.*, vol. 15, no. 8, pp. 2561-2565, Nov. 2007]

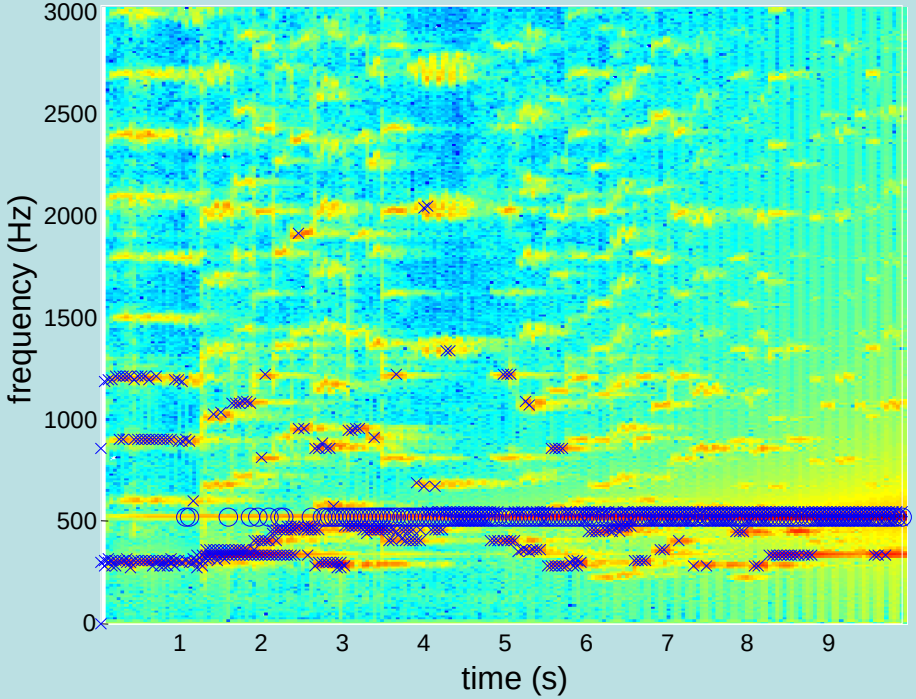


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Howling detection: formal problem definition



- example signal fragment:
  - source signal = violin (44.1 kHz)
  - measured feedback path (0.1 s)
  - gain slightly above MSG (0.33 dB)
- data set generation:
  - data set = candidate howling comp.
  - generation: DFT+peak picking (N=3)

o = positive realizations (N_P = 166)
x = negative realizations (N_N = 482)

- binary hypothesis test:
  - $\mathcal{H}_0$: howling does not occur (Null hypothesis)
  - $\mathcal{H}_1$: howling does occur (Alternative hypothesis)
- detection performance:
  - probability of detection $P_D = P(\mathcal{H}_1;\mathcal{H}_1) = \frac{N_{TP}}{N_P}$ reliability
  - probability of false alarm $P_{FA} = P(\mathcal{H}_1;\mathcal{H}_0) = \frac{N_{FP}}{N_N}$ sound quality



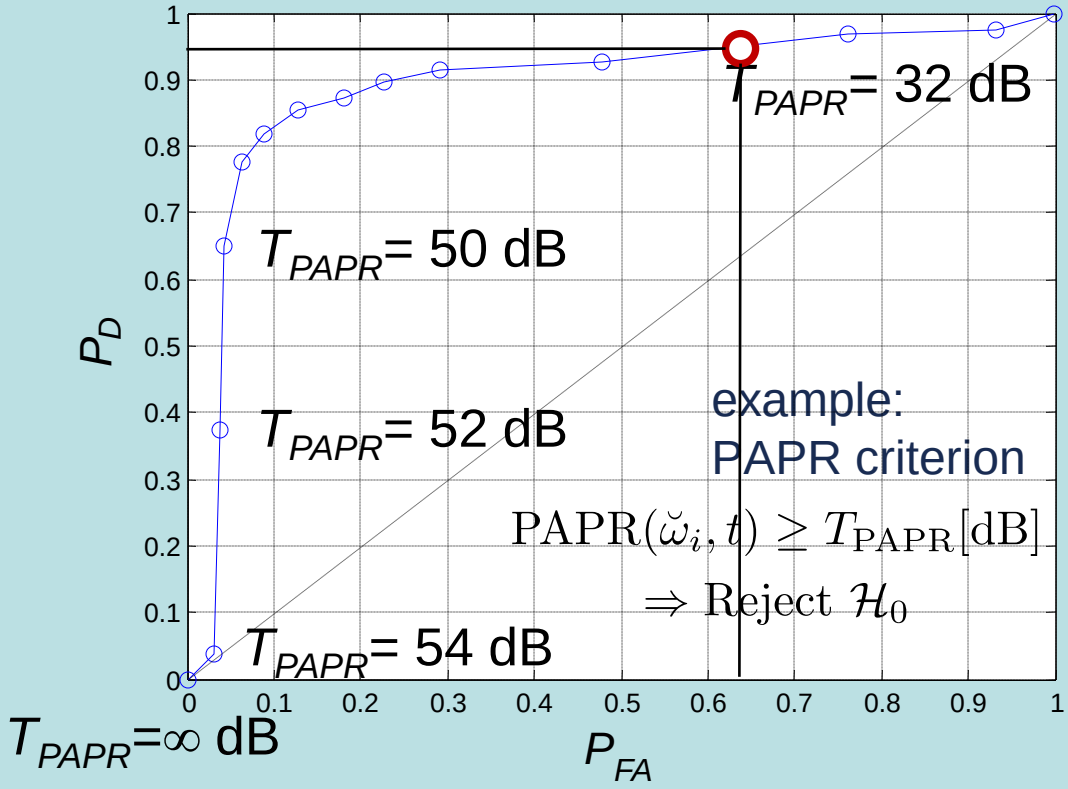
Howling detection: signal features

- Spectral signal features for howling detection:
  1. Peak-to-Threshold Power Ratio (PTPR)
     = howling should only be suppressed when it is sufficiently loud
  2. Peak-to-Average Power Ratio (PAPR)
     = howling eventually has large power compared to speech/audio
  3. Peak-to-Harmonic Power Ratio (PHPR)
     = howling does not exhibit a harmonic structure (≠ in case of clipping!)
  4. Peak-to-Neighboring Power Ratio (PNPR)
     = howling is a non-damped sinusoid, having approx. zero bandwidth
- Temporal signal features for howling detection
  1. Interframe Peak Magnitude Persistence (IPMP)
     = howling components typically persist longer than speech/audio
  2. Interframe Magnitude Slope Deviation (IMSD)
     = howling exhibits an exponential amplitude buildup over time



Howling detection: single-feature criteria

- single-feature howling detection criteria:
  - each of these 6 signal features can be used to define a single-feature howling detection criterion
- receiver operating characteristic (ROC) curve:
  - P_D vs. P_{FA} for entire range of possible threshold values



T_{PAPR}=–∞ dB

T_{PAPR}=∞ dB

- performance comparison:

  P_{FA} for fixed P_D = 95 %

criterion	P_{FA}
PTPR	70 %
PAPR	63 %
PHPR	37 %
PNPR	33 %
IPMP	54 %
IMSD	40 %



Howling detection: multiple-feature criteria

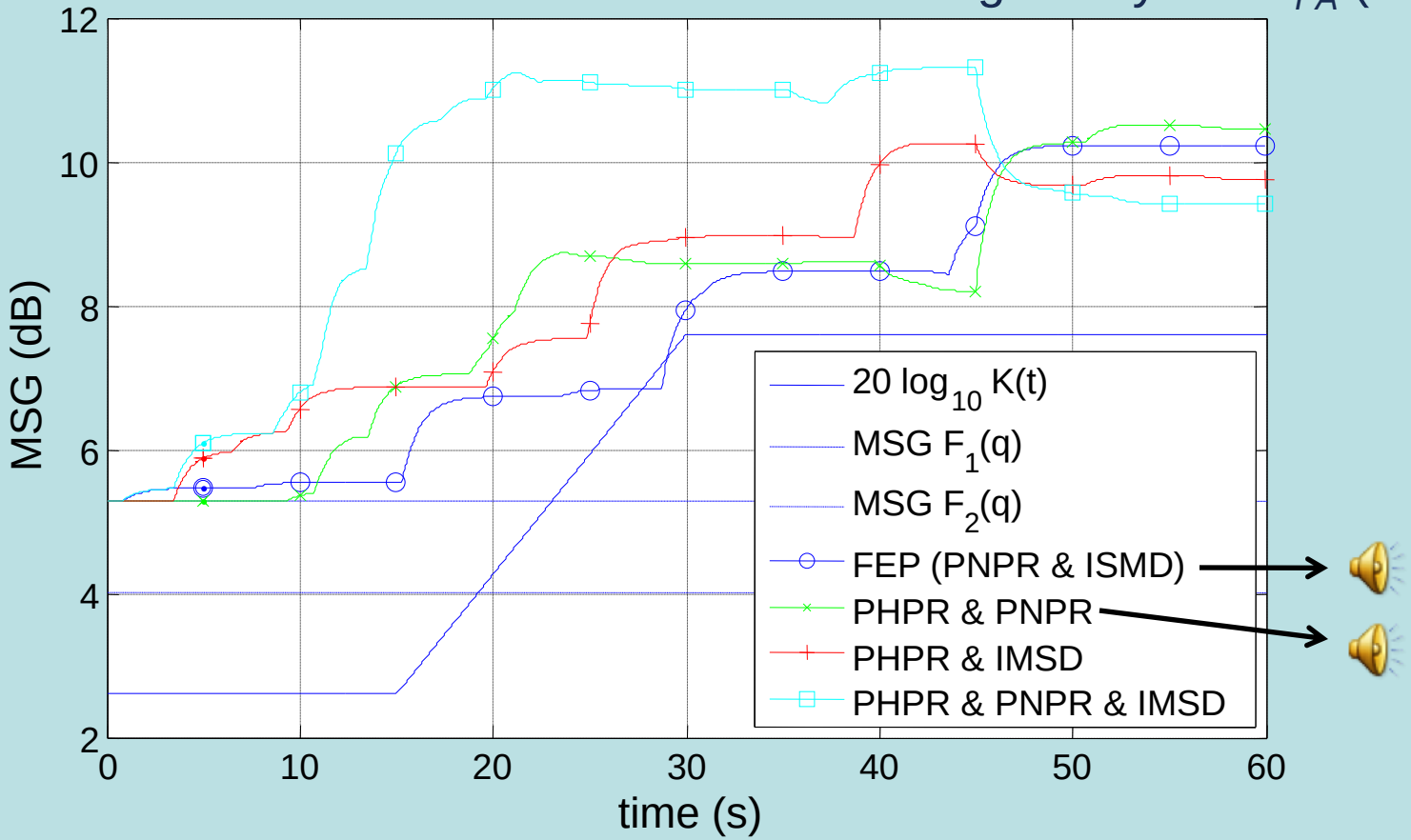
- existing multiple-feature criteria:
  - design guideline: 1 spectral feature + 1 temporal feature
  - PHPR & IPMP [Lewis *et al.* (Sabine Inc.), 1993]
  - FEP = PNPR & IMSD [Osmanovic *et al.*, 2007]
- novel multiple-feature criteria:
  - design guideline: combine features with high P_D, regardless of P_{FA}

single-feature criterion	P_{FA}	multiple-feature criterion	P_{FA}
PTPR	70 %	PHPR & IPMP	65 %
PAPR	63 %	FEP	24 %
PHPR	37 %	PHPR & PNPR	14 %
PNPR	33 %	PHPR & IMSD	25 %
IPMP	54 %	PNPR & IMSD	5 %
IMSD	40 %	PHPR & PNPR & IMSD	3 %



Howling detection: NHS simulation results

- practical issue: lack of notch filter de-activation criteria!
  - need to set detection threshold such as to get very low P_{FA} (= 1 %)



- novel vs. existing howling detection criteria:
  - slightly higher MSG, slighly lower sound quality, higher reliability



Conclusion

- Objective evaluation of howling detection criteria:
  - formal definition of howling detection problem
  - relationship between detection performance measures and acoustic feedback control performance measures
  - evaluation of single-feature criteria based on ROC curves
- Novel multiple-feature howling detection criteria
  - single-feature criteria are not sufficient for howling detection in audio applications ($P_{FA} \geq 33$ % for fixed $P_D = 95$ %)
  - design guideline for existing multiple-feature criteria is not ideal ($P_{FA} \geq 24$ % for fixed $P_D = 95$ %)
  - novel design guideline: combine features with high P_D, regardless of P_{FA} ($P_{FA} \geq 3$ % for fixed $P_D = 95$ %)
- Simulation results:
  - reliability of NHS method is clearly improved
  - work ahead: need for notch filter de-activation criteria