Active Noise Control of Speech in Headphones
using Linear Prediction

22. december 2016

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Linear Prediction
Group 761

Introduction
What is Active Noise
Control (ANC)
Problem of ANC

Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system

Simulations Results
Linear Prediction
Parameters
Attenuation Performance
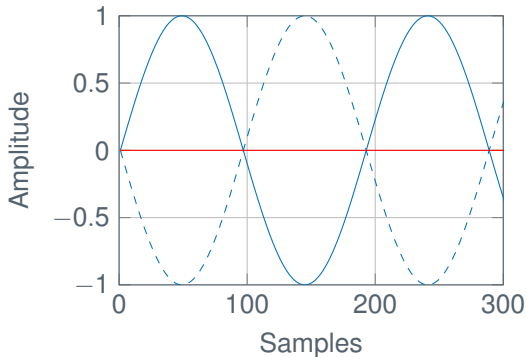
Discussion
Computational Cost

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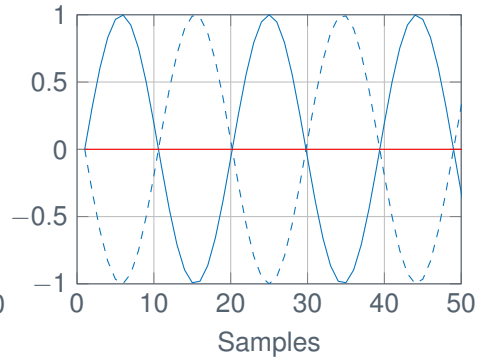Aalborg University
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Introduction
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Problem of ANC

Methods
Feedforward FXLMS
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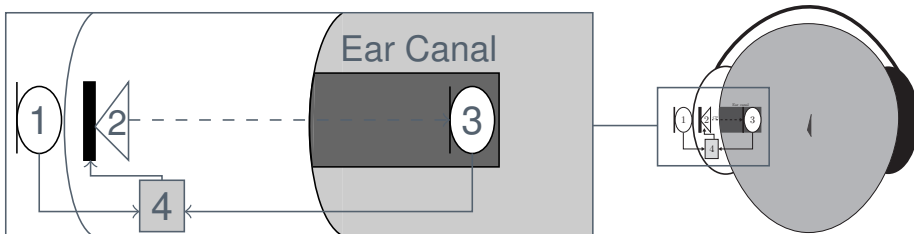Combined system

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▶ The basic theory of ANC
  ▶ 250 Hz
  ▶ 2500 Hz

— Original signal
-- Counterphase signal
— Error

▶ Headphone cups attenuate high frequencies passively
▶ Lower frequencies must be attenuated actively
▶ Feedforward system
  ▶ 1: Reference microphone
  ▶ 2: Headphone loudspeaker
  ▶ 3: Error microphone
  ▶ 4: Digital signal Processor (DSP)

▶ Problem with feedforward
▶ Sampling and reconstruction delay
  ▶ Anti Aliasing filter
  ▶ Reconstructions filter
▶ The measured delay of a
  Σ/Δ-converter - TLV320AIC3204
▶ Spacing between microphones
  ▶ Min: 75.5 mm
  ▶ Max: 302 mm

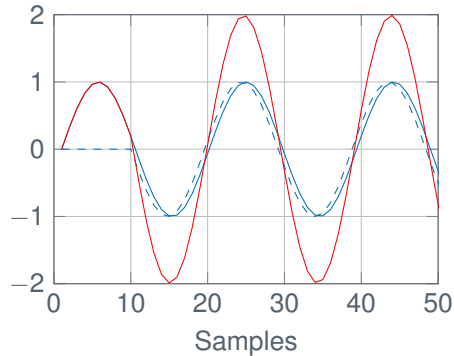| f_s [kHz]	48	96	192
Delay [μs]	900	450	225
Delay [samples]	43	43	43

► Counterphase signal delayed 10 samples
  ► 250 Hz
  ► 2500 Hz

— Original signal
- - Counterphase signal
— Error

- ▶ Periodic noise is easy to cancel
- ▶ Signal Characteristics
    - ▶ Periodic Signals
        - ▶ Strict Sense Stationary (SSS)
    - ▶ Speech Signals
        - ▶ Quasiperiodic
        - ▶ 50 Hz – 4000 Hz
        - ▶ Can be assumed Wide Sense Stationary (WSS) for 20 ms – 30 ms
- ▶ Speech noise is difficult to cancel

► How well does the consumer headphones attenuate?

  ► Denon AH-GC20   2.200 kr (2016)
  ► Bose QC25   2.799 kr (2016)
  ► Bose QC15   2.696 kr (2011)
  ► BeoPlay H8   3.495 kr (2016)
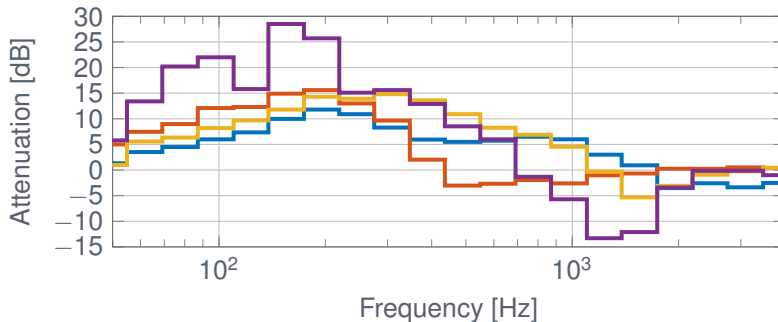
▶ ANC ideally attenuate infinitely

▶ Delays are introduced by sampling and reconstruction

▶ Periodic signals can be attenuated infinitely

▶ Speech signals are not attenuated very well

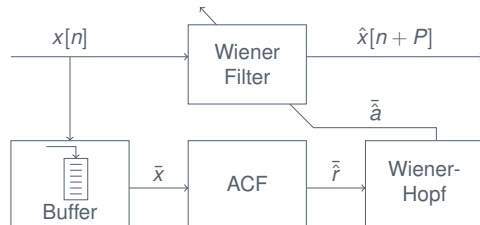Combining a feedforward ANC algorithm with a Linear prediction (LP) scheme to compensate for delay.

- ▶ Control filter
  - ▶ Transfer function from (1) to (2)
  - ▶ Adaptive
- ▶ Cancelation path
  - ▶ Transfer function from (2) to (3)
  - ▶ Linear time-invariant
- ▶ Adaptive FXLMS-algorithm
  - ▶ Optimization problem
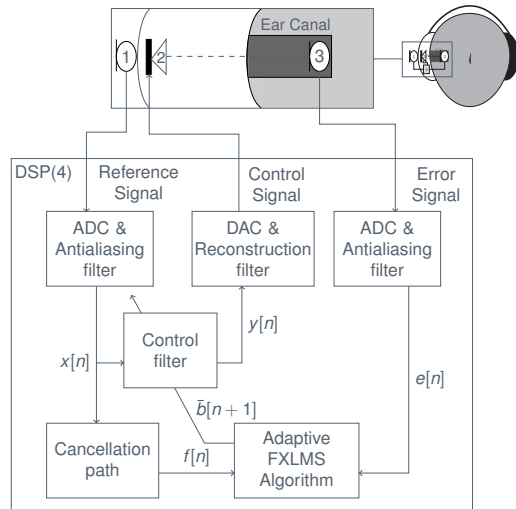
- ▶ Auto Correlation Function estimation
  - ▶ Framelength N
  - ▶ Overlap O
- ▶ Wiener-hopf equation: $\hat{\bar{R}}\bar{\bar{a}} = -\bar{\bar{r}}$
  - ▶ Inverting matrix
  - ▶ Levinson-Durbin
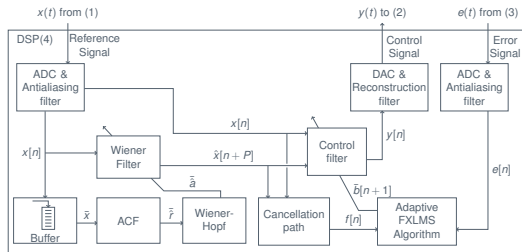- ▶ Wiener filtering in cascade
  - ▶ Prediction length P

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► Multirate Processing for reducing
  conversion delay
    ► High sample rate
    ► Low processing rate
► Smaller prediction length
    ► 10 instead of 43

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▶ Input for control filter and CP
  ▶ $x[n]$
  ▶ $\hat{x}[n + P]$

- ► Delays are introduced due to sampling and reconstruction
- ► Delays are reduced using multirate processing
- ► Compensation by Linear Prediction using Wiener filtering
- ► Noise cancelling using a feedforward FXLMS-algorithm

- ► Simulink
- ► Archimedes Project
- ► Prediction Gain
- ► Filter banks vs Fourier transform
- ► Listening tests

- ▶ Prediction order P = 43
- ▶ Optimal parameters
  - ▶ Framelength N = 1600
  - ▶ Overlap O = 1500
- ▶ Prediction Gain PG = 5.4 dB
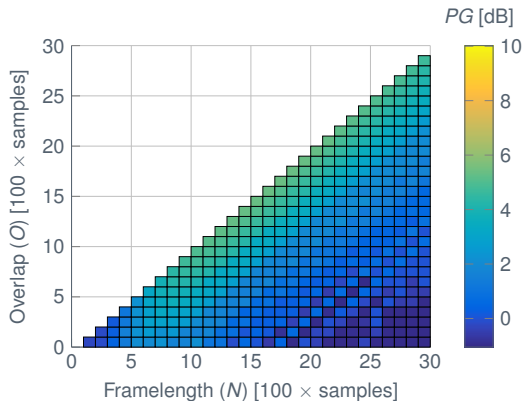
- Prediction order P = 10
- Optimal parameters
  - Framelength N = 1200
  - Overlap O = 1100
- Prediction Gain PG = 10 dB
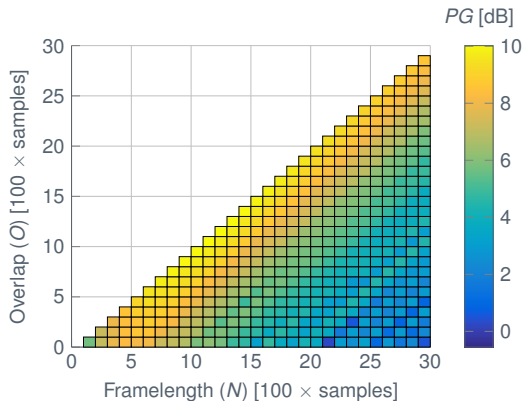
► ANC attenuation with
varying system delay
  ► Feedforward FXLMS
  ► Feedforward LP FXLMS
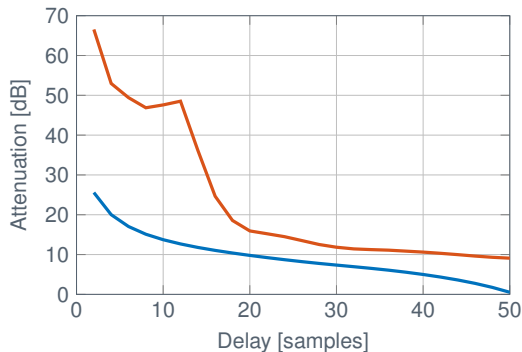
Simulation Results
Frequency response

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▶ Frequency response
  ▶ Feedforward FXLMS
  ▶ Feedforward LP FXLMS
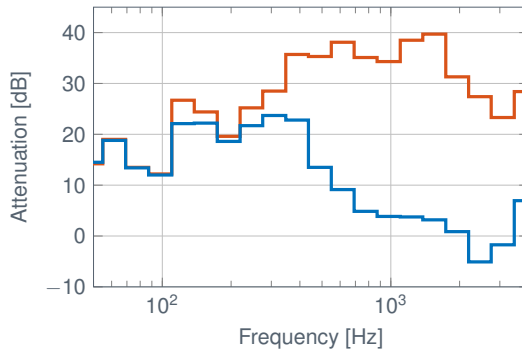
- Computational cost of System (instructions pr. sample)
    - Linear Prediction: 55000
    - Feedforward FXLMS: 4000
    - Multirate: ≤ 100

Questions?