Active Noise Control of Speech in Headphones
using Linear Prediction

22. december 2016

Christian Claumarch, Kasper Kiis Jensen
Maxime Démurger, Mikkel Krogh Simonsen
Oliver Palmhøj Jokumsen
16gr761@es.aau.dk

Acoustics and Audio Technology - Fall 2016
Department of Electronic Systems
Aalborg University
Denmark

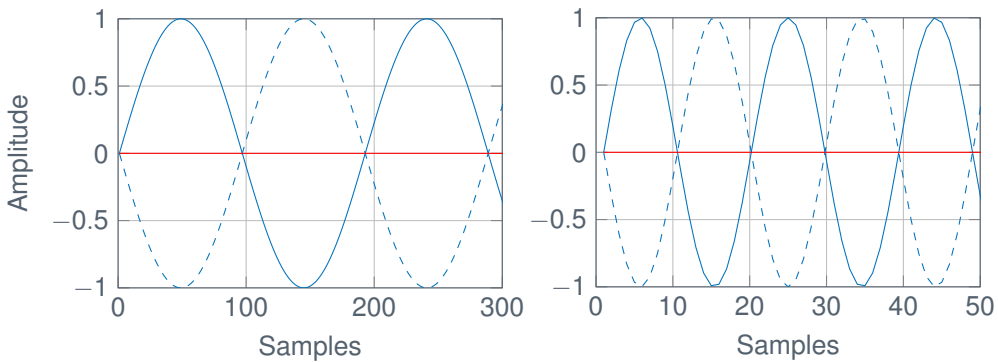
AALBORG UNIVERSITY
DENMARK

Agenda

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

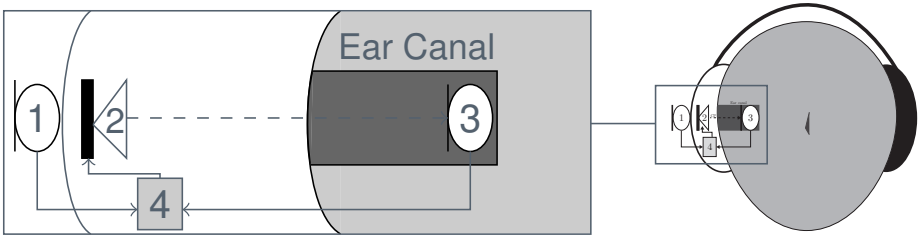
Active Noise Control of Speech in Headphones using Linear Prediction
Group 761
Introduction
What is Active Noise Control (ANC) 2
Problem of ANC
Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

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



Active Noise Control of Speech in Headphones using 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

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



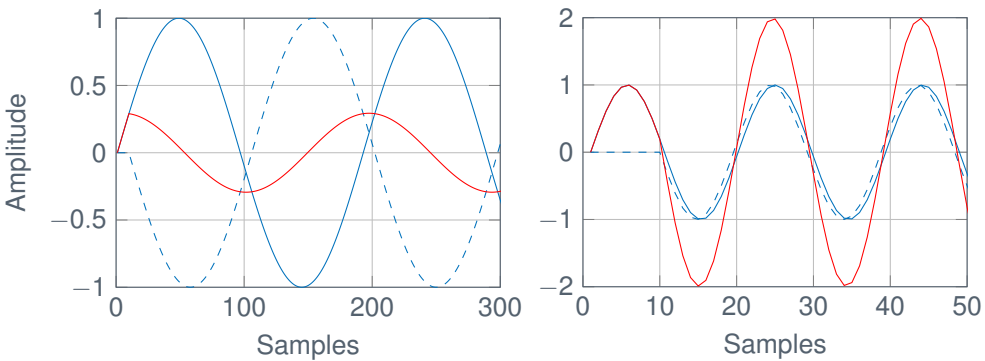
Active Noise Control of Speech in Headphones using Linear Prediction
Group 761
Introduction
What is Active Noise Control (ANC)
Problem of ANC
Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

- Feedforward problem
- Sampling and reconstruction delay.
  - Anti Aliasing filter
  - Reconstructions filter
- The measured delay of a Sigma Delta 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

Active Noise Control of Speech in Headphones using Linear Prediction
Group 761
Introduction
What is Active Noise Control (ANC)
Problem of ANC 5
Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

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

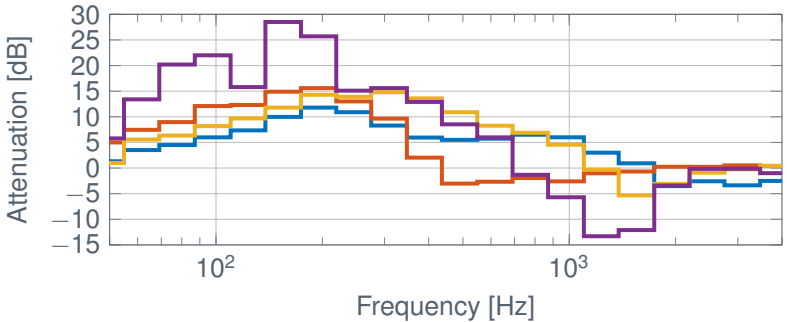


Active Noise Control of Speech in Headphones using Linear Prediction
Group 761
Introduction
What is Active Noise Control (ANC)
Problem of ANC
Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

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

Active Noise Control of Speech in Headphones using 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

- 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)



Active Noise Control of Speech in Headphones using 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

- ANC ideally attenuate infinitely
- Delays are introduced by sampling and reconstruction
- Periodic signals can be attenuated infinitely
- Speech signals are not attenuated very well

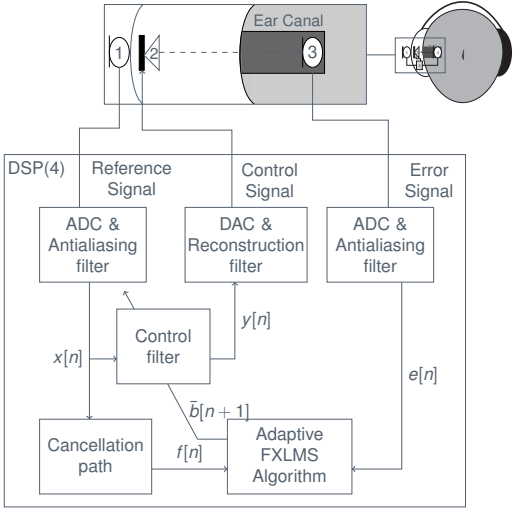
Active Noise Control of Speech in Headphones using Linear Prediction
Group 761

Introduction
What is Active Noise Control (ANC)
Problem of ANC 9
Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

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

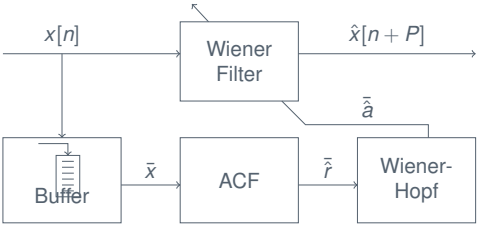
Active Noise Control of Speech in Headphones using Linear Prediction
Group 761
Introduction
What is Active Noise Control (ANC)
Problem of ANC
Methods
Feedforward FXLMS 10
Linear Prediction
Multirate Processing
Combined system
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

- 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



Active Noise Control of Speech in Headphones using 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

- Auto Correlation Function estimation
  - Framelength N
  - Overlap O
- Wiener-hopf equation: $\hat{R}\bar{\hat{a}} = -\bar{\hat{r}}$
  - Inverting matrix
  - Levinson-Durbin
- Wiener filtering in cascade
  - Prediction length P



Methods
Multirate Processing

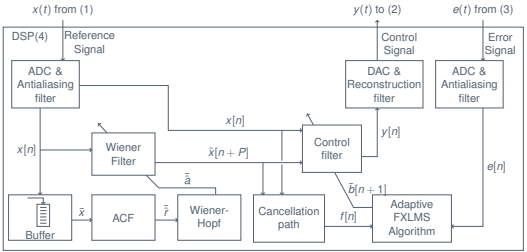
Active Noise Control of Speech in Headphones using Linear Prediction
Group 761
Introduction
What is Active Noise Control (ANC)
Problem of ANC
Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

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

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

Active Noise Control of Speech in Headphones using Linear Prediction
Group 761
Introduction
What is Active Noise Control (ANC)
Problem of ANC
Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system
13
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

- Input for control filter and CP
  - $x[n]$
  - $\hat{x}[n+P]$
- CP delayed for compensation of error microphone delay



Active Noise Control of Speech in Headphones using 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

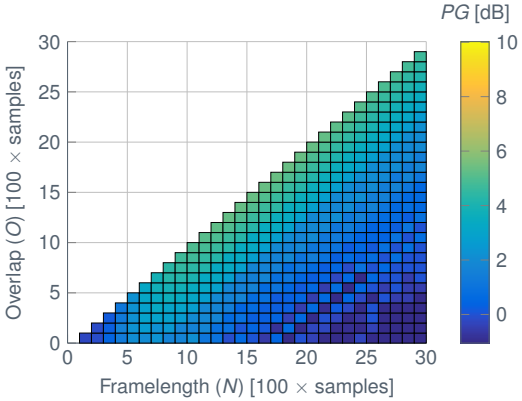
- Delays are introduced due to sampling and reconstruction
- Delays are reduced using multirate processing
- Compensation by Linear Prediction using Wiener filtering
- Noise cancelling using a feedforward FXLMS-algorithm

Active Noise Control of Speech in Headphones using 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 15
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

- Simulink
- Prediction Gain
- Filter banks vs Fourier transform
- Not entirely sure what to put here

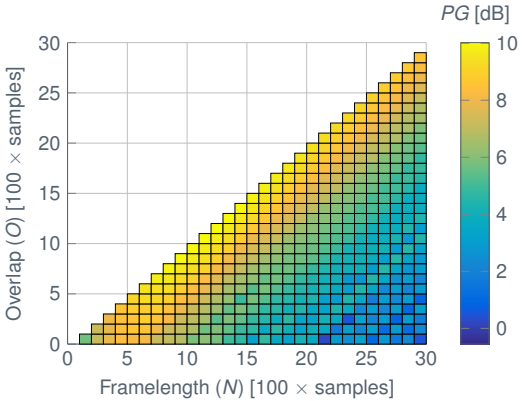
Active Noise Control of Speech in Headphones using Linear Prediction
Group 761
Introduction
What is Active Noise Control (ANC)
Problem of ANC
Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

- Prediction order P = 43
- Optimal parameters
  - Framelength N = 1600
  - Overlap O = 1500
- Prediction Gain PG = 5.4 dB



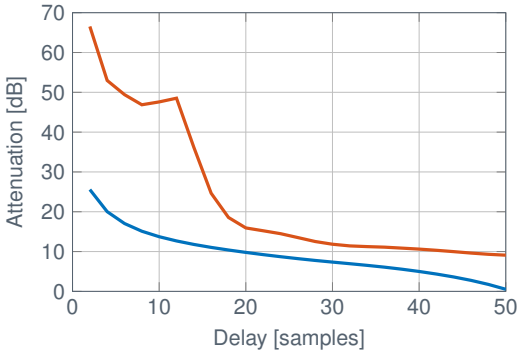
Active Noise Control of Speech in Headphones using Linear Prediction
Group 761
Introduction
What is Active Noise Control (ANC)
Problem of ANC
Methods
Feedforward FXLMS
Linear Prediction
Multirate Processing
Combined system
Simulations Results
Linear Prediction Parameters
Attenuation Performance
Discussion
Computational Cost

- Prediction order P = 10
- Optimal parameters
  - Framelength N = 1200
  - Overlap O = 1100
- Prediction Gain PG = 10 dB



Simulation Results
Attenuation Performance

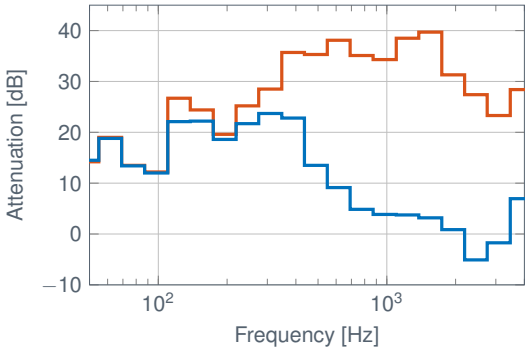
- ANC attenuation with varying system delay
  - Feedforward FXLMS
  - Feedforward LP FXLMS



Simulation Results
Frequency response

Active Noise Control of Speech in Headphones using 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 19
Discussion
Computational Cost

- Frequency response
  - Feedforward FXLMS
  - Feedforward LP FXLMS



Active Noise Control of Speech in Headphones using 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 20

- Computational cost of System (instructions pr. sample)
  - Linear Prediction: 55000
  - Feedforward FXLMS: 4000
  - Multirate: ≤ 100
- Figure missing of different DSP maximum instruction pr sample at 48 kHz

Questions?

AALBORG UNIVERSITY
DENMARK