

Active Noise Control of Speech in Headphones

using Linear Prediction

December 22nd 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

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

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

Introduction

What Is ANC?

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

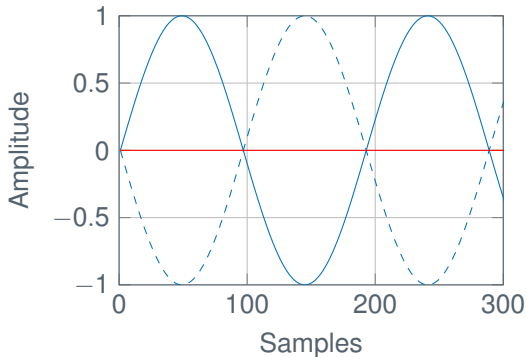
Acoustics and Audio
Technology
Dept. of Electronic Systems
Aalborg University
Denmark

2

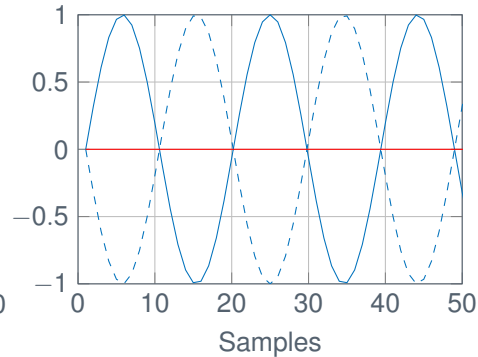
20

► The basic theory of ANC

- 250 Hz
- 2500 Hz



- Original signal
- - Counterphase signal
- Error



Introduction

How Does ANC Work?

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

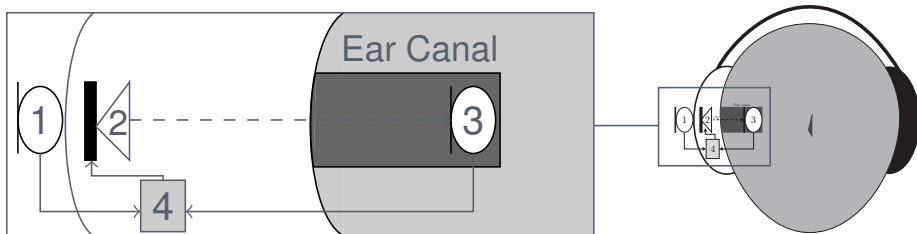
Discussion

Computational Cost

Acoustics and Audio
Technology
Dept. of Electronic Systems
Aalborg University
Denmark

3

- ▶ 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)



20

Introduction

Problem of ANC

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

Introduction

What is Active Noise
Control (ANC)

Problem of ANC

4

Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

Simulations Results

Linear Prediction

Parameters

Attenuation Performance

Discussion

Computational Cost

- ▶ 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 [μ s]	900	450	225
Delay [samples]	43	43	43

Introduction

Problem of ANC

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

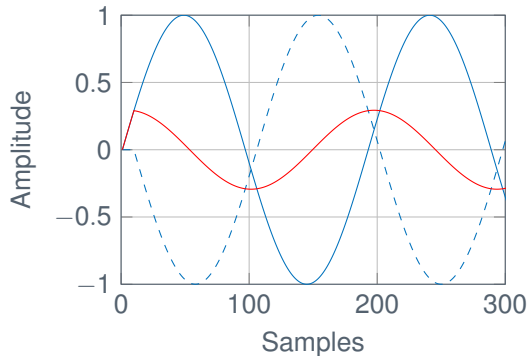
Computational Cost

5

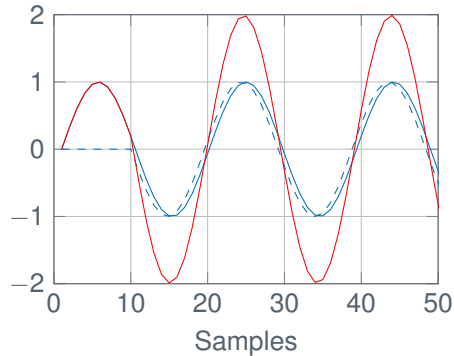
20

▶ Counterphase signal delayed 10 samples

- ▶ 250 Hz
- ▶ 2500 Hz



- Original signal
- - Counterphase signal
- Error





Introduction

Speech vs. Periodic Noise

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

Introduction

What is Active Noise
Control (ANC)

Problem of ANC

6

Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

Simulations Results

Linear Prediction

Parameters

Attenuation Performance

Discussion

Computational Cost

- ▶ 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

Introduction

Present Consumer Headphones

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

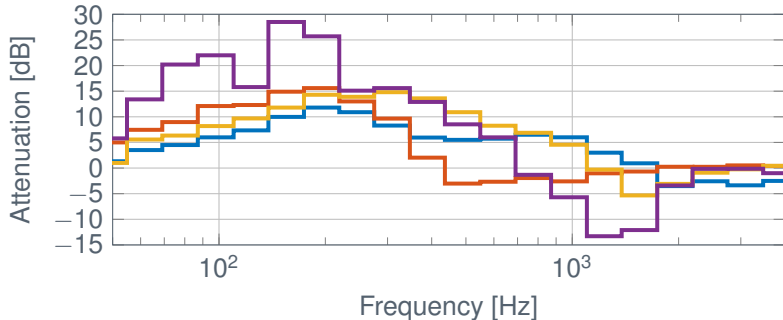
Discussion
Computational Cost

Acoustics and Audio
Technology
Dept. of Electronic Systems
Aalborg University
Denmark

7

► How well does the consumer headphones ANC 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)



20



Introduction

Summary

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

8

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

20



Introduction

A solution for the problem

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.

20

Methods

Feedforward 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

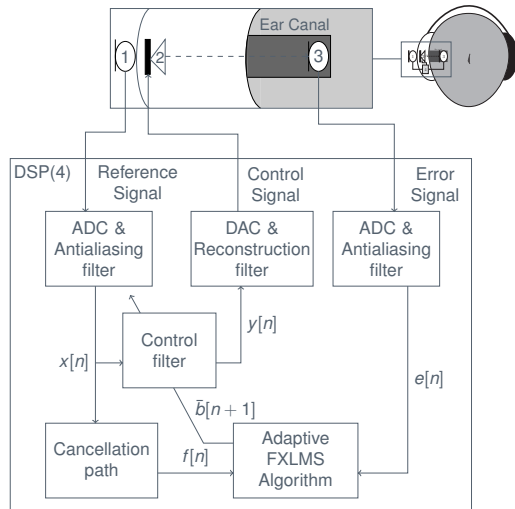
Linear Prediction
Parameters
Attenuation Performance

Discussion

Computational Cost

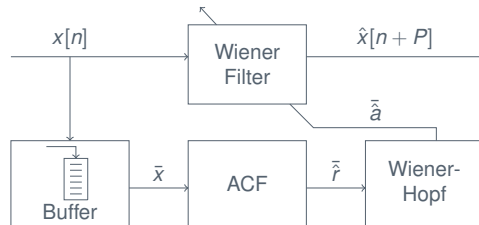
10

- ▶ Control filter
 - ▶ Transfer function from (1) to (2)
 - ▶ Adaptive
- ▶ Cancellation path
 - ▶ Transfer function from (2) to (3)
 - ▶ Linear time-invariant
- ▶ Adaptive FXLMS-algorithm
 - ▶ Optimization problem



20

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

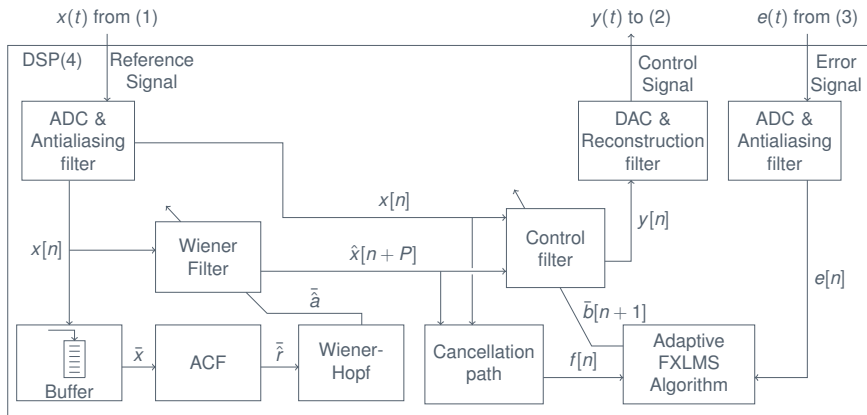


- ▶ Multirate processing for reducing conversion delay
 - ▶ High sample rate
 - ▶ Low processing rate
- ▶ Smaller prediction length
 - ▶ 10 instead of 43

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

► Input for control filter and CP

- $x[n]$
- $\hat{x}[n + P]$





Methods

Summary

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

14

- ▶ 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

20



Simulation Results

How to Test

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

- ▶ Simulink
- ▶ Archimedes Project
- ▶ Prediction Gain
- ▶ Filter-banks vs. Fourier transform
- ▶ Listen to results

15

20

Simulation Results

Optimal parameters

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

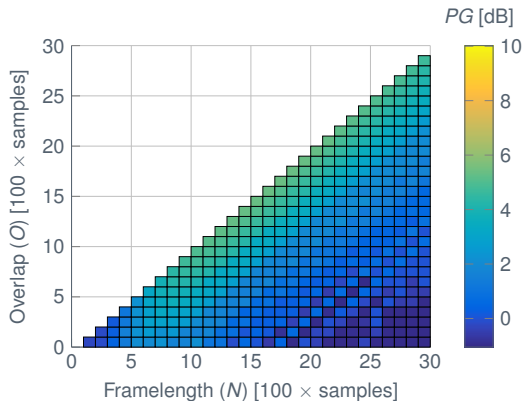
Simulations Results

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



16

20

Simulation Results

Optimal parameters

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

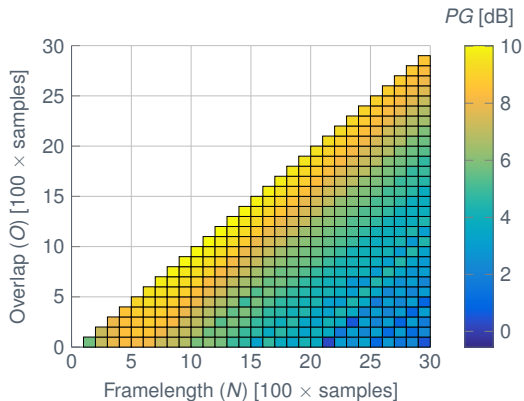
Linear Prediction
Parameters
Attenuation Performance

Discussion

Computational Cost

17

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



20

Simulation Results

Attenuation Performance

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

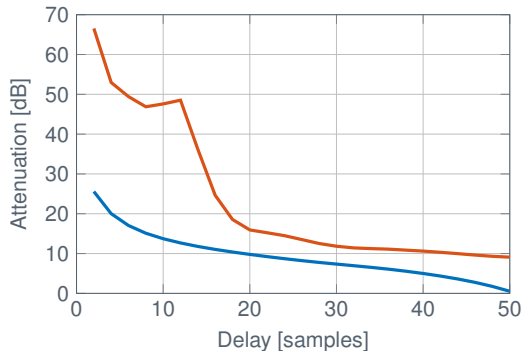
Linear Prediction
Parameters
Attenuation Performance

18

Discussion

Computational Cost

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



20

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

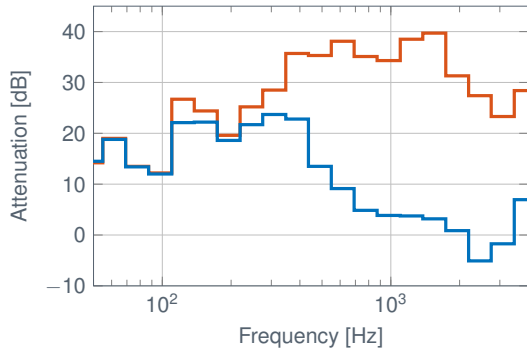
19

Discussion

Computational Cost

20

- Frequency response
 - Feedforward LP FXLMS
 - Feedforward FXLMS





Discussion

Computational Cost

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

- ▶ Proof of concept
- ▶ Computational cost of system (instructions per sample)
 - ▶ Linear Prediction: $> 50,000$
 - ▶ Feedforward FXLMS: $> 4,000$
 - ▶ Multirate: < 100

20

Questions?



AALBORG UNIVERSITY
DENMARK