Statistical signal processing through applications

ADAPTIVE FILTERING

Problem description:

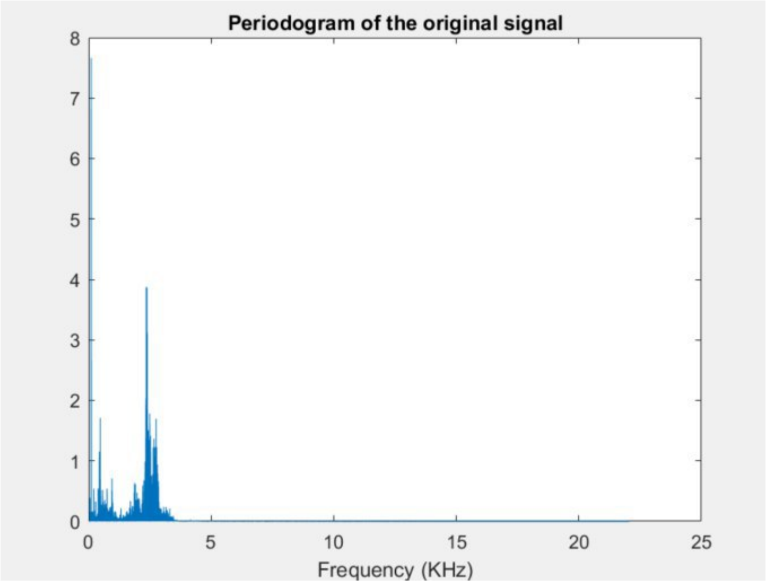
- Noisy signal (bass signal + talking noise)
- Recorded noise (External talking noise)
- Want to clean the signal to not hear the talking noise.

- Difficulty: Reverb effect affects the recorded noise. Situation may not be static.

Starting point:

- Bass + talking noise:

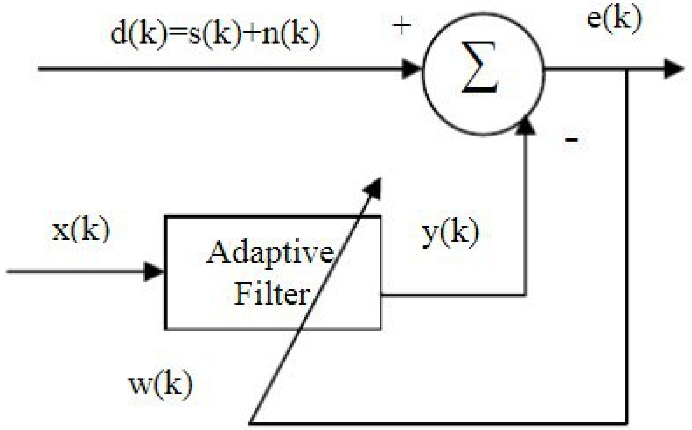
- Recorded talking noise:



Sampling Frequency: 44.1kHz

Methods

- Estimate adaptive filter coefficients w(k) in order to be able to clean the bass signal e(k)



To deal with non-static situation, adaptive solutions:

- LMS
- NLMS
- RLS

LMS algorithm summary

Parameters

- P = filter order = 800 (18 ms as fs = 44.1k)
- μ = step size = 0.0003
  - λmax =

$$0 < \mu < \frac{2}{\lambda max}$$

Initialization

- $\hat{h}(0) = 0$ or random

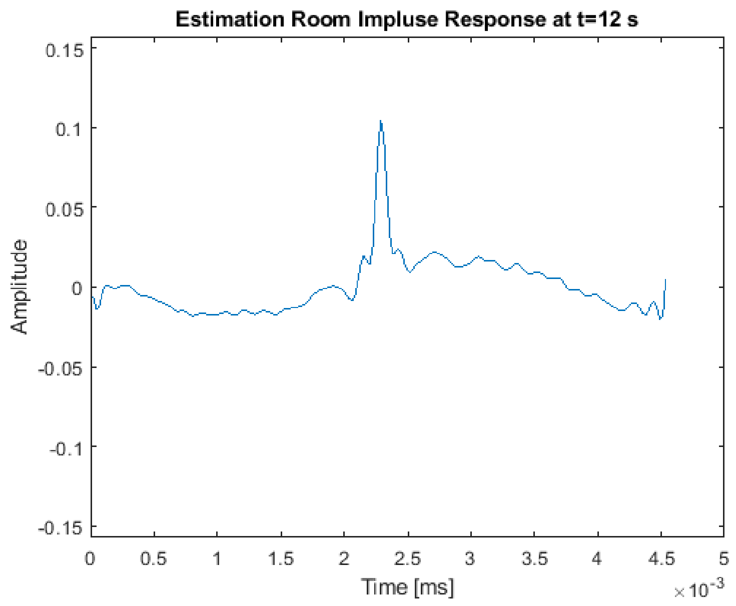
Computation

- Computation: For n = 0, 1, 2...
- $X(n) = [x(n), x(n-1), \ldots, x(n-p+1)]^T$
- $e(n) = d(n) - \hat{h}^H(n)\, X(n)$
- $\hat{h}(n+1) = \hat{h}(n) + \mu\, e^*(n)\, X(n)$

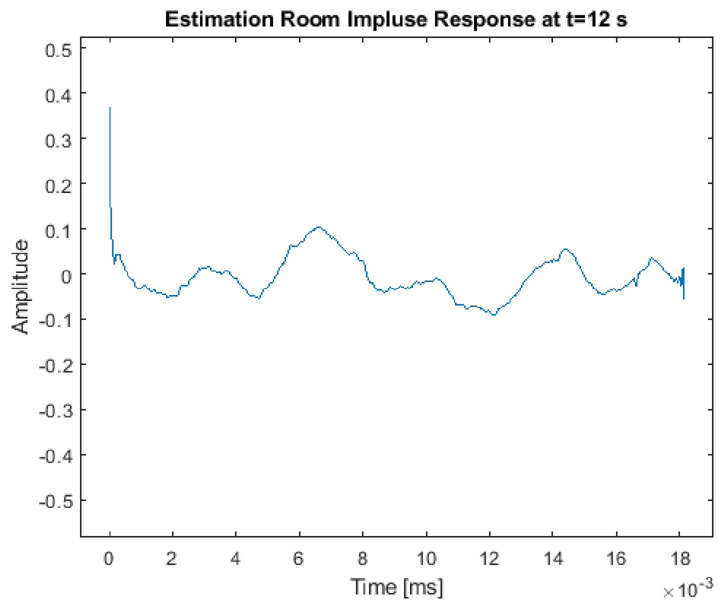
LMS results

Estimated Impulse Response

Offline

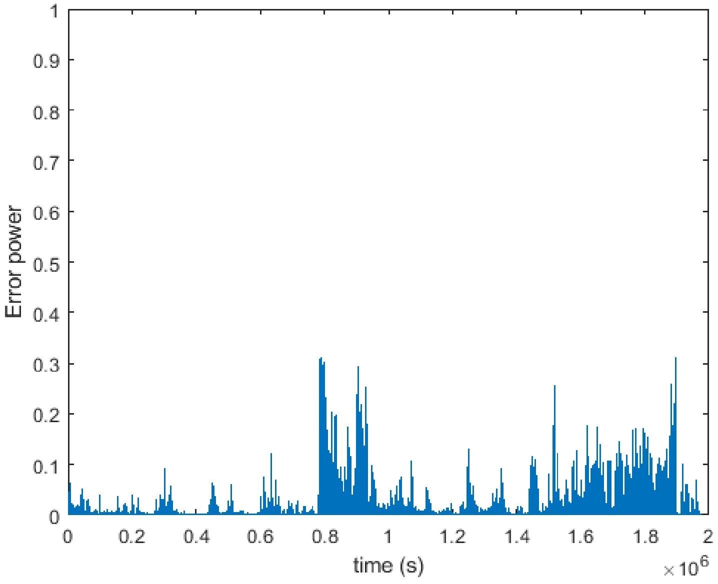


On the fly



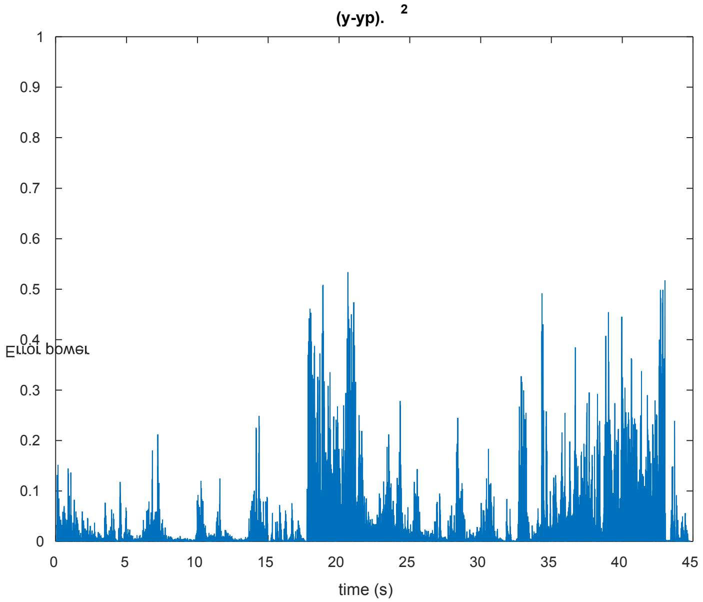
LMS results

Mean square error



Offline

Mean square error



On the fly

NLMS algorithm summary

Parameters

- P = filter order = 800 (18 ms as fs = 44.1k)
- μ = step size = 0.003*Nf*mean(x.^2)

Initialization

- $\hat{h}(0) = 0$ or random

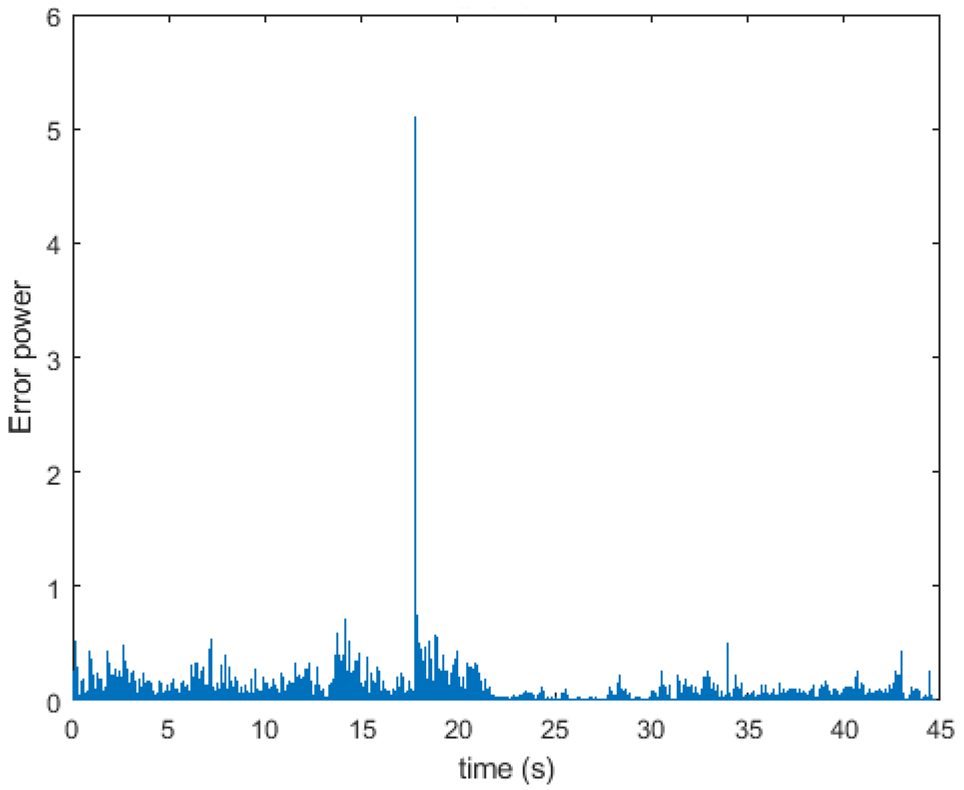
Computation

- Computation: For n = 0, 1, 2...
- $X(n) = [x(n), x(n-1), \ldots, x(n-p+1)]^T$
- $e(n) = d(n) - \hat{h}^H(n)\, X(n)$
- $\hat{h}(n+1) = \hat{h}(n) + \frac{\mu\, e^*(n)\, X(n)}{X^H(n)\, X(n)}$

NLMS results

NLMS

- Play sound



RLS Algorithm Summary

Parameters

- P = 300 samples,
- Signal downsampled to 11kHz
- λ = forgetting factor= 0.999

Initialization

- ĥ (0) = random (cannot be zero)

Computation

- P is correlation matrix
- Batch is the u vector

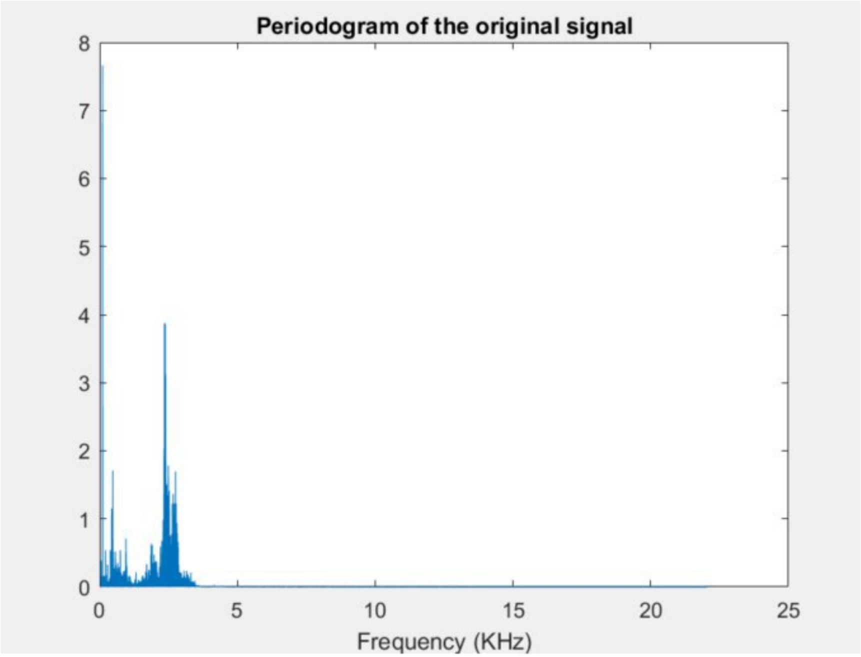
$$
\begin{aligned}
\underline{k}(n) &= \frac{\lambda^{-1}P(n-1)\underline{u}(n)}{1+\lambda^{-1}\underline{u}^T(n)P(n-1)\underline{u}(n)} \\
\alpha(n) &= d(n) - \underline{u}(n)^T\underline{w}(n-1) \\
\underline{w}(n) &= \underline{w}(n-1) + \underline{k}(n)\alpha(n) \\
P(n) &= \lambda^{-1}P(n-1) - \lambda^{-1}\underline{k}(n)\underline{u}^T(n)P(n-1)
\end{aligned}
$$

RLS results

RLS

- Play sound

graphs



Comparison

	Filter order	Mse using only past samples	Mse using past&future samples
Noisy signal		0,0568	
LMS	800 (offline 200)	0,0338	0.004
NLMS	800	0,0435	
RLS	300	0.0022	

Thank you, any questions?