ROBUST AND LOW-COST CASCADED NON-LINEAR ACOUSTIC ECHO CANCELLATION

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Outline

Acoustic Echo Approach

Echo problem

- echo $\Longrightarrow$ loudspeaker signal picked up by the microphone
- echo and network delay $\Longrightarrow$ disturb communication

Approach

Acoustic Echo Cancellation (AEC)

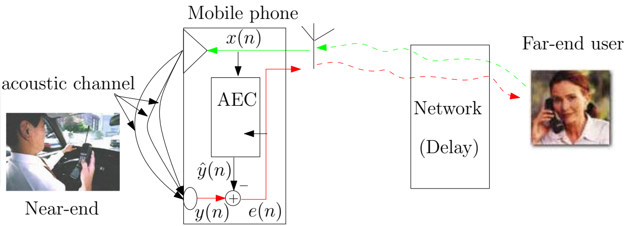

Figure: AEC approach

Linear Acoustic Echo Cancellation

characteristics

- linear environment:

  $y(n) = h(n) * x(n)$
- non-linear environments:

  ~~$y(n) = h(n) * x(n)$~~

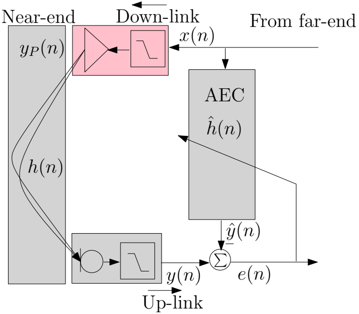

Figure: Non-linear loudspeaker

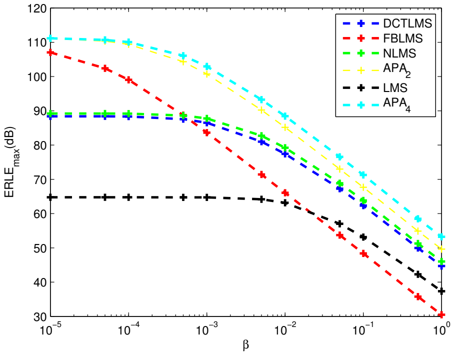

Figure: Loudspeaker non-linearity effect,

$$y_P(n) = x(n) + \beta x^3(n)$$

Baseline Non-linear Acoustic Echo Cancellation

characteristics

- non-linearity in acoustic path
- requires more computation capacity
- slow convergence
- depends on the model accuracy

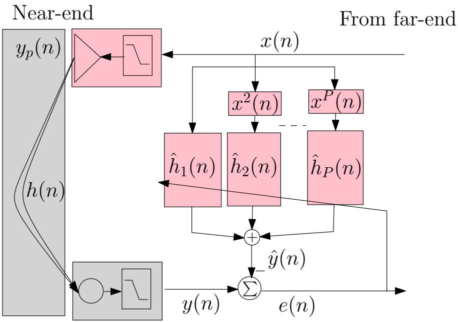

Figure: Non-linear AEC system

Non-linearity Source and Model

non-linear part

loudspeaker

- non-linear filter
- small impulse responses
- slow variability

linear part

acoustic channel

- linear filter
- longer impulse response
- high variability

microphone

- linear filter
- small impulse response
- low variability

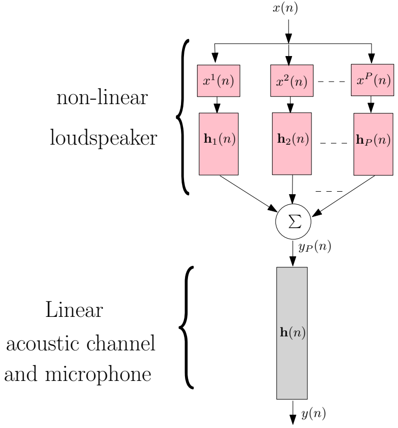

Figure: Proposed model

Objectives

proposed approach

- pre-processor ⇒ loudspeaker model [1, 2, 3]
- loudspeaker model ⇒ non-linear power filter [4, 5]
- power filter model from loudspeaker measurements [5]
- advantage: robustness during acoustic channel changes

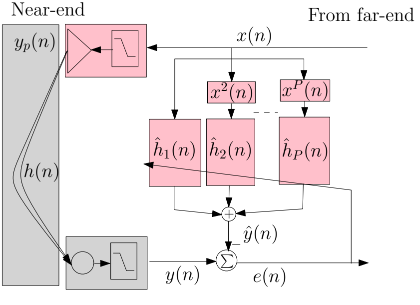

Figure: Parallel non-linear AEC approach

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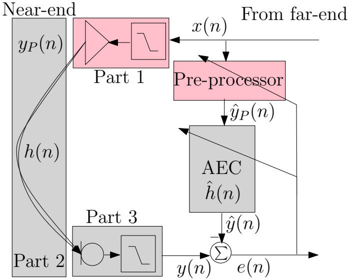


Figure: Cascaded non-linear AEC approach

Non-linear AEC Approaches

parallel or cascaded approach?

- $\tilde{h}_p(n) \Longrightarrow \hat{h}_p(n) * \hat{h}(n)$
- parallel approach reach low minimum error
- parallel approach re-estimate all taps during acoustic channel changes

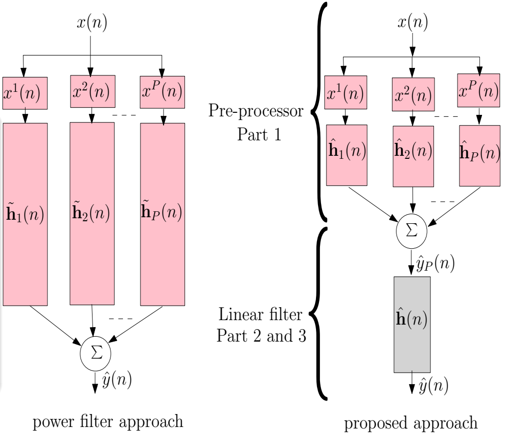


Figure: Parallel and cascaded approach

Filter Estimation
Signal Expression

- echo signal:

$$y_p(n) = \mathbf{h}_p(n)\mathbf{x}_p(n)$$

$$y(n) = \mathbf{h}(n)\sum_{p=1}^{P}\mathbf{y}_p(n)$$

- estimated echo signal:

$$\hat{y}_p(n) = \hat{\mathbf{h}}_p(n)\mathbf{x}_p(n)$$

$$\hat{y}(n) = \hat{\mathbf{h}}(n)\sum_{p=1}^{P}\hat{\mathbf{y}}_p(n)$$

- error signal:

$$e(n) = y(n) - \hat{y}(n)$$

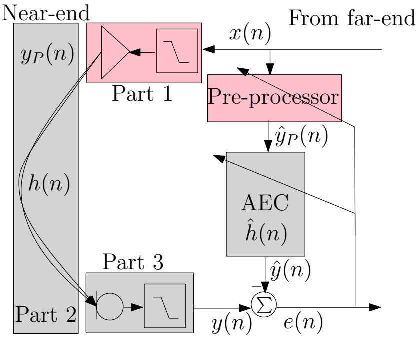


Figure: Cascaded non-linear AEC system

Filters Estimation
MMSE Estimator of Filters [6]

AEC Linear Filter

$$\hat{\mathbf{h}} = \mathbf{r}_{y,y_P} \mathbf{R}_{y_P}^{-1} \quad (1)$$

$\mathbf{r}_{y,y_P}$: cross-correlation
$\mathbf{R}_{y_P}$: auto-correlation

Comments
- depends on the loudspeaker signal
- $\mathbf{R}_{y_P} \Rightarrow$ determines convergence rate

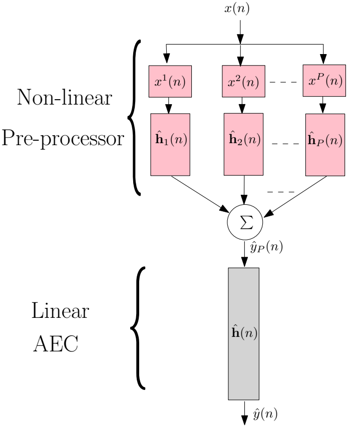


Figure: Proposed model

Filters Estimation
MMSE Estimator of Filters [6]

Pre-processor Sub-filters

$$\hat{\mathbf{h}}_{p_k} = \left(\mathbf{r}_{y,\tilde{y}_{p_k}} - \mathbf{r}_{Y_{p \neq p_k},\tilde{y}_{p_k}}\right)\mathbf{R}^{-1}_{y_{p_k}} \qquad (1)$$

$\tilde{y}_k(n) = x^{p_k}(n) * h(n)$

$\mathbf{r}_{y,\tilde{y}_{p_k}}, \mathbf{r}_{Y_{p \neq p_k},\tilde{y}_{p_k}}$: cross-correlation

$\mathbf{R}_{y_{p_k}}$: auto-correlation

Comments

- $\mathbf{r}_{Y_{p \neq p_k},\tilde{y}_{p_k}}$ $\Rightarrow$ reduces performance
- correlation of input powers
- required of orthogonalization [4]

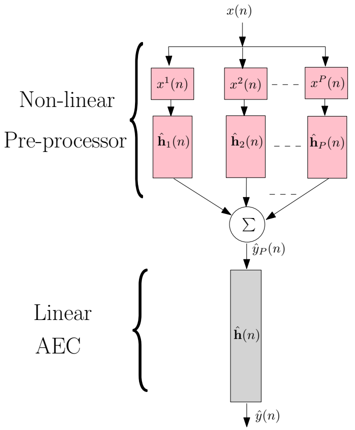


Figure: Proposed model

Filters Estimation

Adaptive Estimation [1, 6]

AEC Linear Filter

$$\hat{\mathbf{h}}(n+1) = \hat{\mathbf{h}}(n) + \mu\hat{\mathbf{Y}}_P(n)e(n)$$

comments

- depends on the pre-processor output
- initialization:$\exists p \setminus h_p(0) \neq 0$

Pre-processor Sub-filters

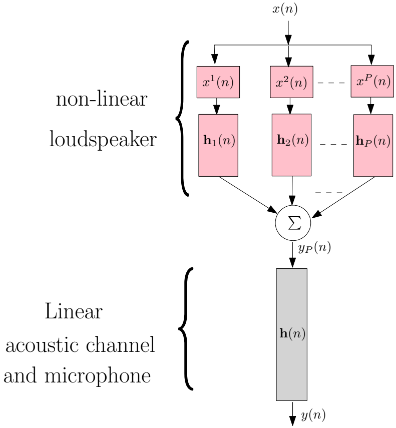
$$\hat{\mathbf{h}}_p(n+1) = \hat{\mathbf{h}}_p(n) + \mu_p \mathbf{X}_p(n)\hat{\mathbf{h}}^T(n)e(n)$$

Comments

- depends on the estimate of the linear filter
- stability (lower step-size)

Test Set-up

- pre-processor sub-filters $P = 5$
- $\mathbf{h}_{p=1,2,3,4,5}(n)$: 100 taps
- $\mathbf{h}(n)$: 200 / 300 taps
- SNR (echo signal to noise ratio) 30 dB / 40 dB



Echo Path Changes (EPC) (10s)

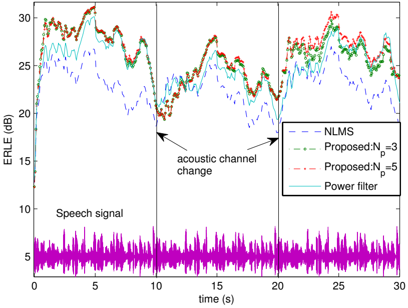
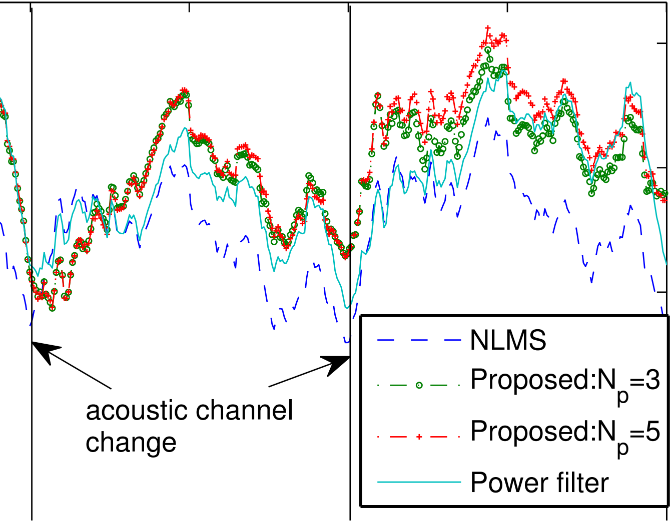


Figure: Comparison of ERLE, 200 taps, SNR=40 dB

common parameters

- initial: better performance
- 1^{st} EPC:pre-processor less accurate
- 2^{nd} EPC: pre-processor more accurate, better ERLE for N_5 than N_3
- proposed model re-converge faster and become more robust to path changes

Echo Path Changes (EPC) (10s)



- 1s
  ac
- 2n
  ac
  N

Echo Path Delay Changes (EPC:10s, delay:2.5ms)

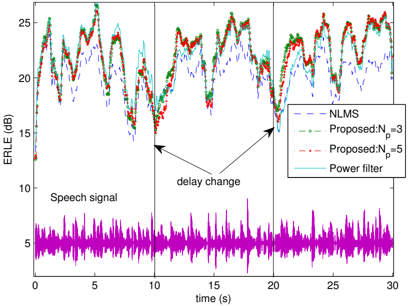
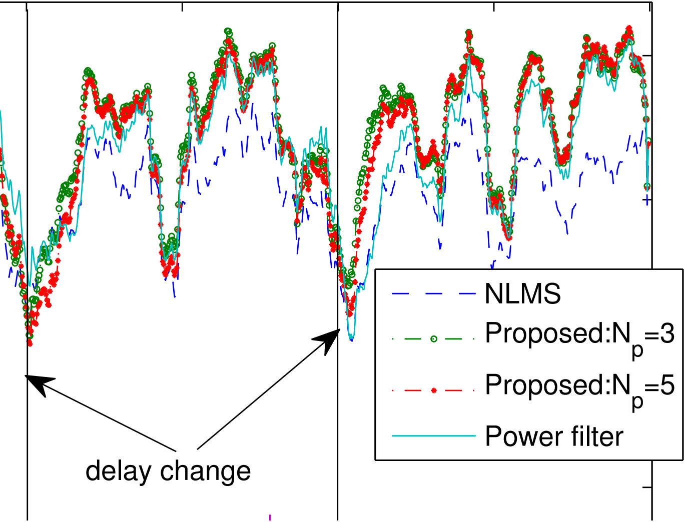


Figure: Comparison of ERLE, delay change, 300 taps, SNR=30 dB

Best tests case

- initial: Similar performance
- 1^{st} EPC: pre-processor not accurate
- 2^{nd} EPC: pre-processor more accurate
- EPC improve the pre-processor accuracy

Echo Path Delay Changes (EPC:10s, delay:2.5ms)



- 1^s
  ac
- 2^n
  ac
- El

Conclusions

Conclusions

- cascaded approach to N-AEC
- robustness against path changes
- robustness in delay changes

Perspectives

- reduce complexity
- pre-processor control with adaptive step-size

END

THANKS FOR YOUR ATTENTION

References

B. S. Nollett and D. L. Jones,
"Adaptation of a memoryless preprocessor for nonlinear acoustic echo cancelling,"
NISP, Sept 1997.

A. Stenger and W. Kellermann,
"Adaptation of a memoryless preprocessor for nonlinear acoustic echo cancelling,"
Signal Processing, vol. 80, pp. 1747–1760, Feb 2000.

A. Guerin, G. Faucon, and R. Le Bouquin-Jeannes,
"Nonlinear acoustic echo cancellation based on volterra filters,"
IEEE Trans. on Speech and Audio Proc., vol. 11, pp. 672 – 683, Nov 2003.

F. Kuech, A. Mitnacht, and W. Kellermann,
"Nonlinear acoustic echo cancellation using adaptive orthogonalized power filters,"
ICASSP, vol. III, pp. 105–108, March 2005.

M. I. Mossi, C. Yemdji, N. W. D. Evans, C. Herglotz, C. Beaugeant, and P. Degry,
"New models for characterizing non-linear distortions in mobile terminal loudspeakers,"
IWAENC, Sept 2010.

S. Haykin,
Adaptive Filter Theory 4^{th} Ed,
Prentice Hall, March 2001.