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NONLINEAR ACOUSTIC ECHO CANCELLATION USING ELITIST RESAMPLING PARTICLE FILTER

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1. Outline

General Task

Acoustic Echo Cancellation (AEC) for hands-free telecommunications and teleconferencing

Challenges

Nonlinear distortions created by amplifiers and transducers in miniaturized communication devices
$\Rightarrow$ Nonlinear AEC (NLAEC)

The EPFES [1]

- Heuristically motivated numerical sampling method
- Performance depends on a tuning parameter

The new method:

The **E**volutionary **R**esampling **P**article **F**ilter **(ERPF)**

- Combination of classical particle filters
- Based on the EPFES but without tuning parameters

2. NLAEC with memoryless preprocessor

Observation model

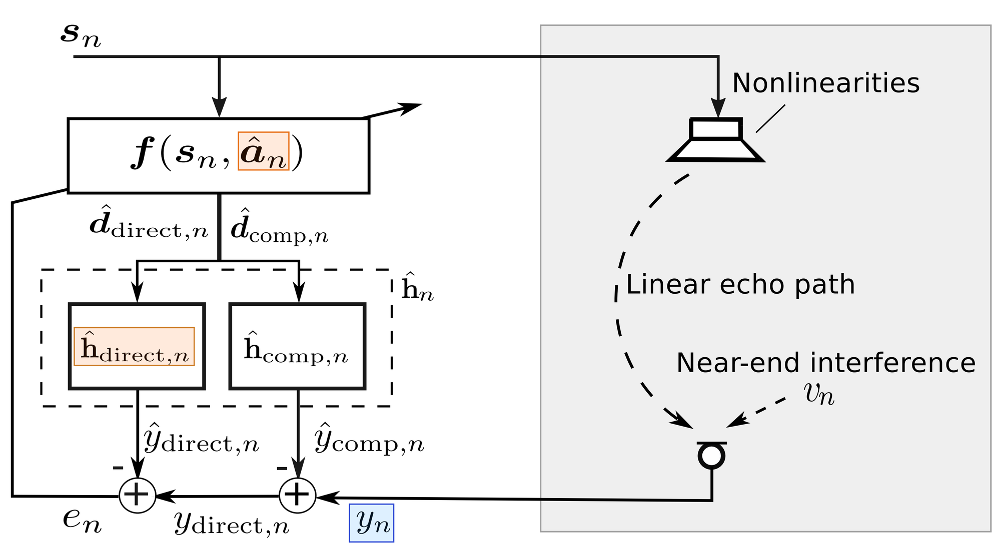
Microphone signal at time instant n $y_n = \mathbf{h}_n^{\mathrm{T}} \boldsymbol{f}(\boldsymbol{s}_n, \boldsymbol{a}_n) + v_n$

- Input signal vector $\boldsymbol{s}_n = [s_n, s_{n-1}, ..., s_{n-M+1}]^{\mathrm{T}}$
- Preprocessor parameter vector $\boldsymbol{a}_n = [a_1, a_2, ..., a_P]^{\mathrm{T}}$

Efficient implementation

The Significance-Aware (SA) filtering [2]

- Exploit information about the linear echo path
- Estimate only direct path component $\hat{\boldsymbol{x}}_n = [\hat{\mathbf{h}}_{\mathrm{direct},n}, \hat{\boldsymbol{a}}_n]^{\mathrm{T}}$



3. The ERPF for NLAEC

Classical Particle Filters

Approximate the posterior density using N_p weighted particles [3]: $p(\boldsymbol{x}_n|y_{1:n}) \approx \sum_{i=1}^{Np} w_n^{(i)} \delta(\boldsymbol{x}_n - \boldsymbol{x}_n^{(i)})$

Sequential Importance Sampling (SIS)

- Preserves all particles (no resampling)
- Degeneracy is unavoidable

Sequential Importance Resampling (SIR)

- Replaces all particles at each iteration
- Sample impoverishment is introduced

Evolutionary Resampling Particle Filter

Hybrid combination of the SIS and SIR preserves elitist particles and resamples only not-elitist particles
Direct derivation leads to a numerical sampling method similar to the EPFES but without the tuning parameter

Weighting

$$w_n^{(i)} \propto \begin{cases} w_{n-1}^{(i)} p(y_n|\boldsymbol{x}_n^{(i)}) & \text{if } \boldsymbol{x}_{n-1}^{(i)} \text{ is an elitist particle} \\ p(y_n|\boldsymbol{x}_n^{(i)}) & \text{if } \boldsymbol{x}_{n-1}^{(i)} \text{ is a not-elitist particle} \end{cases}$$

MMSE estimate

$$\hat{\boldsymbol{x}}_n = \sum_{i=1}^{Np} w_n^{(i)} \boldsymbol{x}_n^{(i)}$$

Selection

$$\boldsymbol{x}_n^{(i)} \begin{cases} \text{elitist particles} & \text{if } w_n^{(i)} \geq w_{\mathrm{th}} \\ \text{not-elitist particle} & \text{if } w_n^{(i)} < w_{\mathrm{th}} \end{cases}$$

Approximation

Estimate $\hat{p}(\boldsymbol{x}_n|y_{1:n})$ using elitist particles

Mutation

Replace not-elitist particles by new particles $\sim \hat{p}(\boldsymbol{x}_n|y_{1:n})$

4. Evaluation

Experimental setup

- Recorded and synthesized nonlinearities
- Time-invariant environment with an SNR of 30 dB

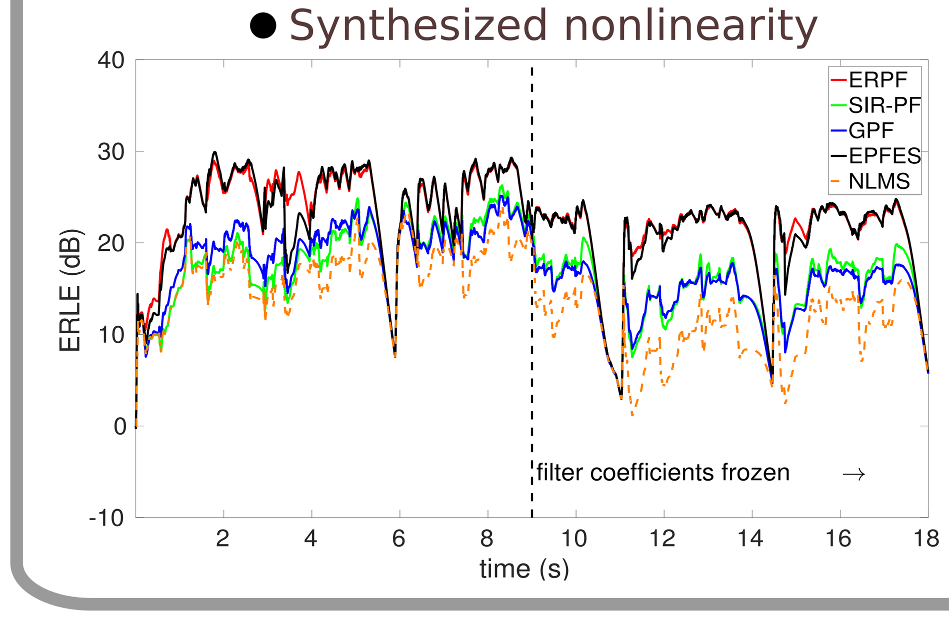
Evaluation

- **E**cho **R**eturn **L**oss **E**nhancement: $\mathrm{ERLE}_n = 10\log_{10}\dfrac{\mathcal{E}\{y_n^2\}}{\mathcal{E}\{e_n^2\}}$ for online adaptation (0s-9s) and for offline (9s-18s)

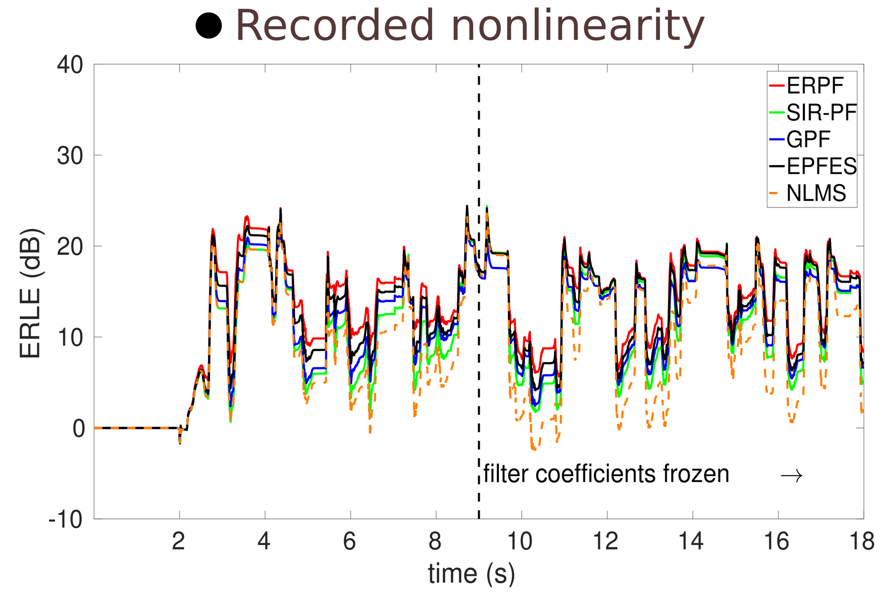
Realization of the ERPF

- M = 256, N_p = 100, f_s = 16kHz
- Legendre polynomials of first kind as basis functions

- Synthesized nonlinearity



- Recorded nonlinearity



	Synthesized		Recorded	
Filter	$\mathrm{ERLE}_{\mathrm{on}}$	$\mathrm{ERLE}_{\mathrm{off}}$	$\mathrm{ERLE}_{\mathrm{on}}$	$\mathrm{ERLE}_{\mathrm{off}}$
ERPF	21.4	21.5	13.8	15.7
EPFES	19.7	21.2	12.9	14.6
SIR-PF	15.4	13.6	11.1	12.9
GPF	16.1	13.3	11.5	13.1
NLMS	14.0	7.4	9.8	9.3

Table 1: Temporal average ERLE for NL-AEC in dB.

5. Conclusions

The ERPF...

- is proposed as a new method for NLAEC
- is formulated as a hybrid combination between two classical particle filters, the SIR and the SIS particle filter
- outperforms the previously proposed EPFES for both recorded and synthesized nonlinearities

References

[1] C. Hümmer *et al.*, "The Elitist Particle Filter Based On Evolutionary Strategies As Novel Approach For Nonlinear Acoustic Echo Cancellation", *IEEE ICASSP*, pp 1315-1319, May 2014.
[2] C. Hofmann *et al.*, "Significance-Aware Filtering For Nonlinear Acoustic Echo Cancellation", *EURASIP Journal on Advances in Signal Processing*, no. 1, pp.1-18, Nov. 2016.
[3] M. Arulampalam *et al.*, "A Tutorial on Particle Filters For Online Nonlinear/Non-Gaussian Bayesian Tracking", *IEEE Transactions on Signal Processing*, vol. 5, pp. 174-188, 2002.

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