Towards Online Monitoring of the Changes in Signal Modality: The Degree of Sparsity

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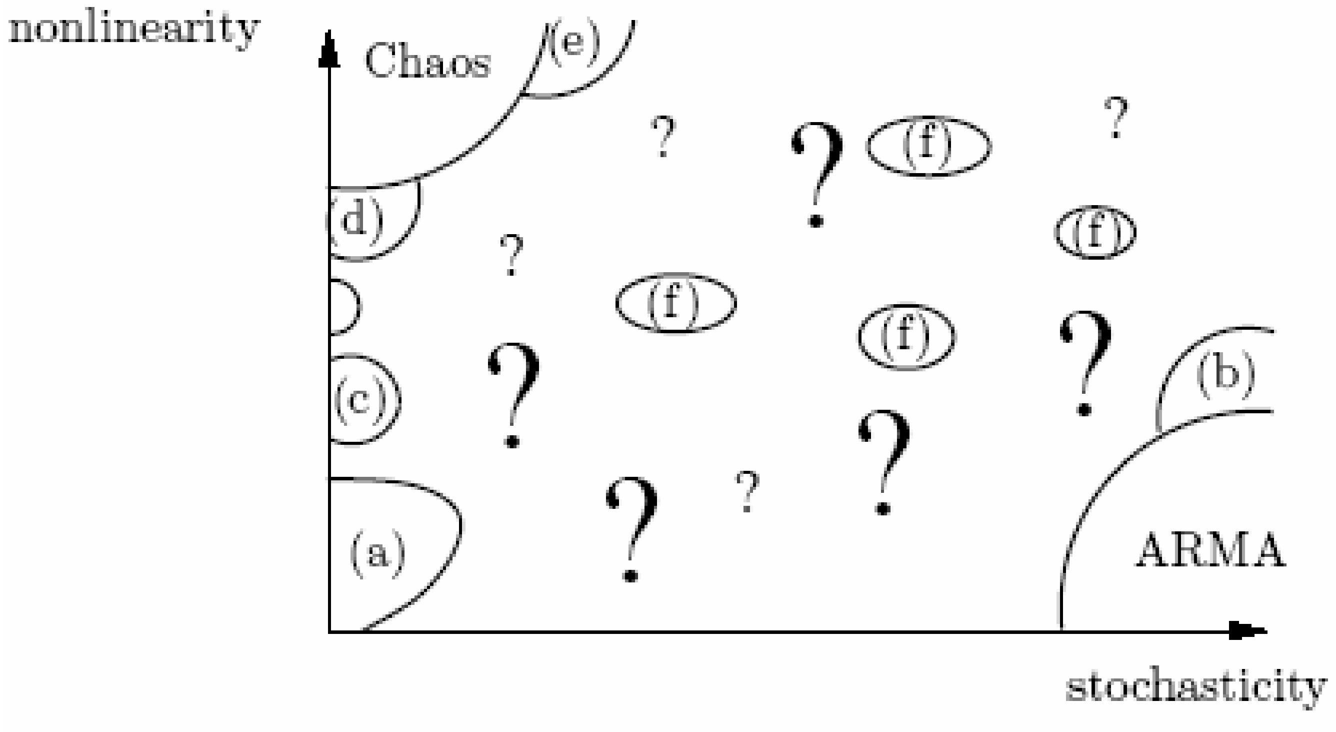
Signal Modality – General Perspective

Notice the difference between **Signal Nonlinearity and System Nonlinearity**

Deterministic vs. Stochatic nature or Linear vs. Nonlinear nature



Change in signal modality can indicate e.g. health hazard (fMRI, HRV)

Challenges in Signal Modality Characterisation

- Changes in the signal nature between (e.g. linear and nonlinear) can reveal **information** which is critical (e.g. health conditions);
- Existing algorithms based on **hypothesis testing** and operate in a batch manner;
- Other methods based on comparing outputs of **two adaptive filters of different kind** $\Rightarrow$ choice of many parameters
- These filters **do not co–operate** $\Rightarrow$ simple test but *non–unique solution*.

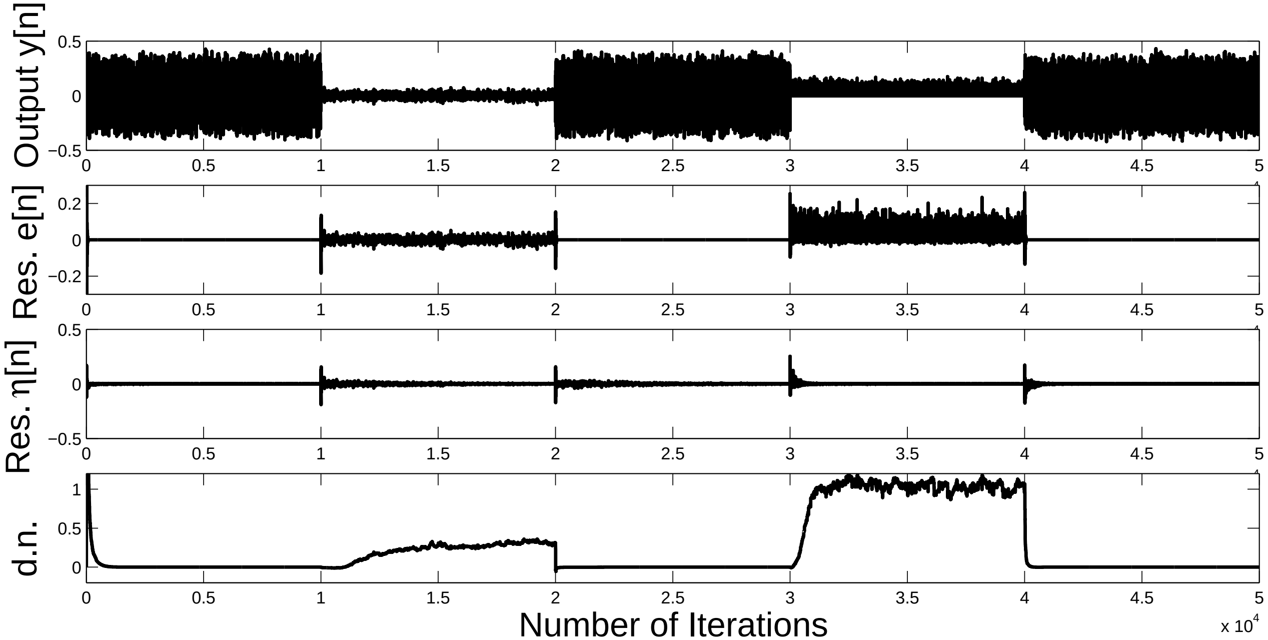
Our aim:- on–line signal modality characterisation for real–world problems

Benefits:- Synergy between the filters, existence and uniqueness of solution

Existing Parametric Methods

Illustration:- Run independently e.g. 3rd order Volterra and LMS FIR filter

Alternate 10,000 "linear" and 10,000 "nonlinear" samples



i) Relies on a parametric model to effectively model the system;

ii) **Slow response**;

ii) Ability to detect changes in nonlinearity particularly suited to the Volterra model.

Hybrid Filters

Key properties:-

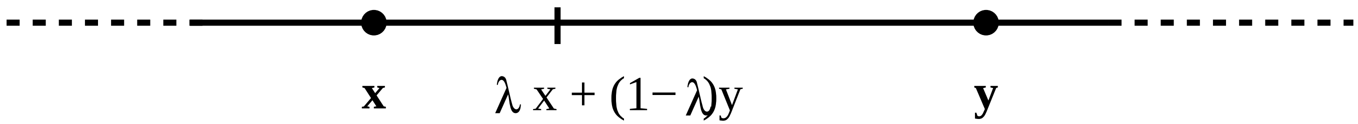
- Multiple individual adaptive subfilters operating in parallel;
- Subfilters feed into a mixing algorithm which produces the single output of the filter;
- Mixing algorithm is also adaptive and combines the outputs of the subfilters **(collaboration, synergy for two different filters**);

Advantages:-

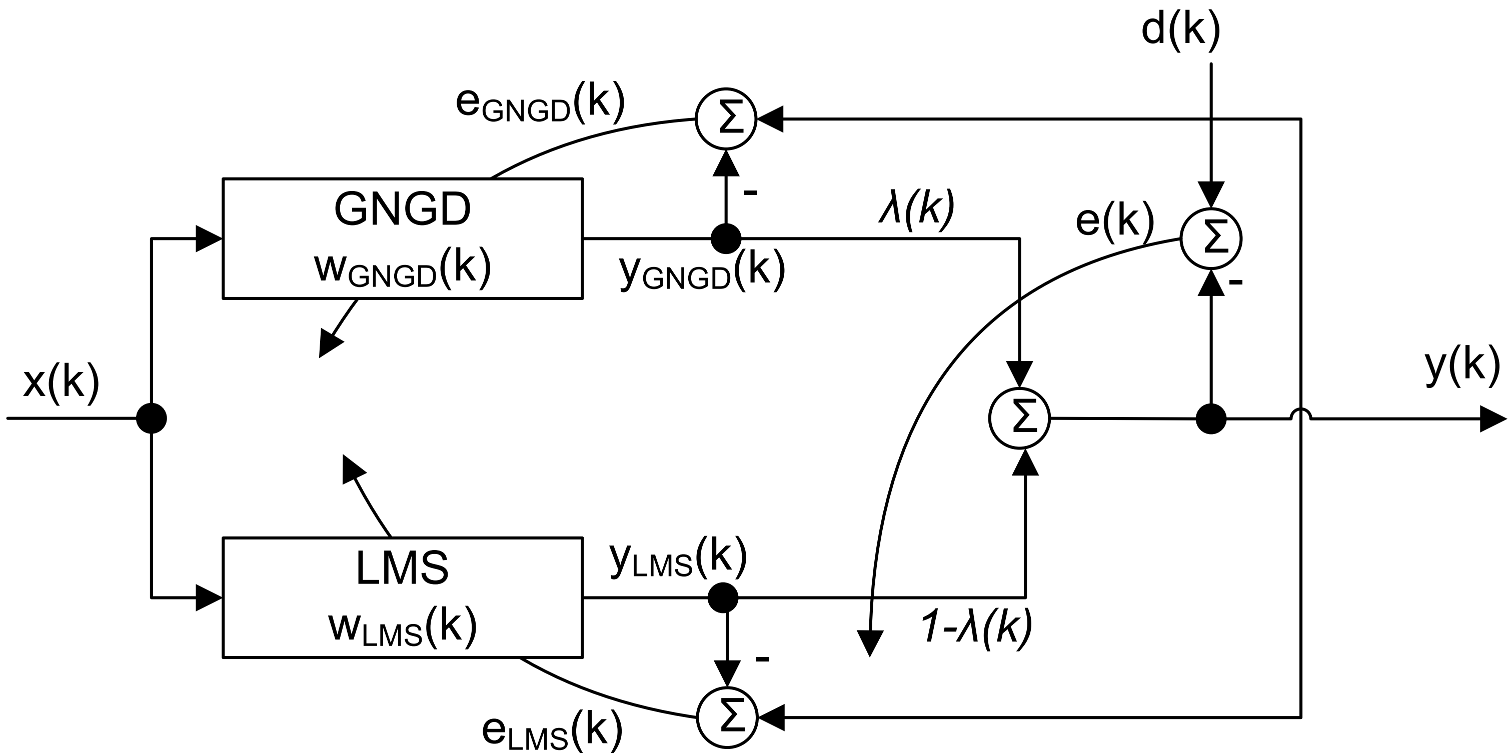
- When in "filtering mode", improved performance over the individual constituent filters;
- One effect of this mixing algorithm is that it can give an indication of which filter is currently responding to the input signal most effectively;
- By selecting algorithms which are suitable for either linear or nonlinear signals $\Rightarrow$ the mixing algorithm can adapt according to fundamental properties of the input signal.

Convex Hybrid Filtering Configuration - Nonlinearity

Virtues of Convex Combination ($\lambda \in [0,1]$)

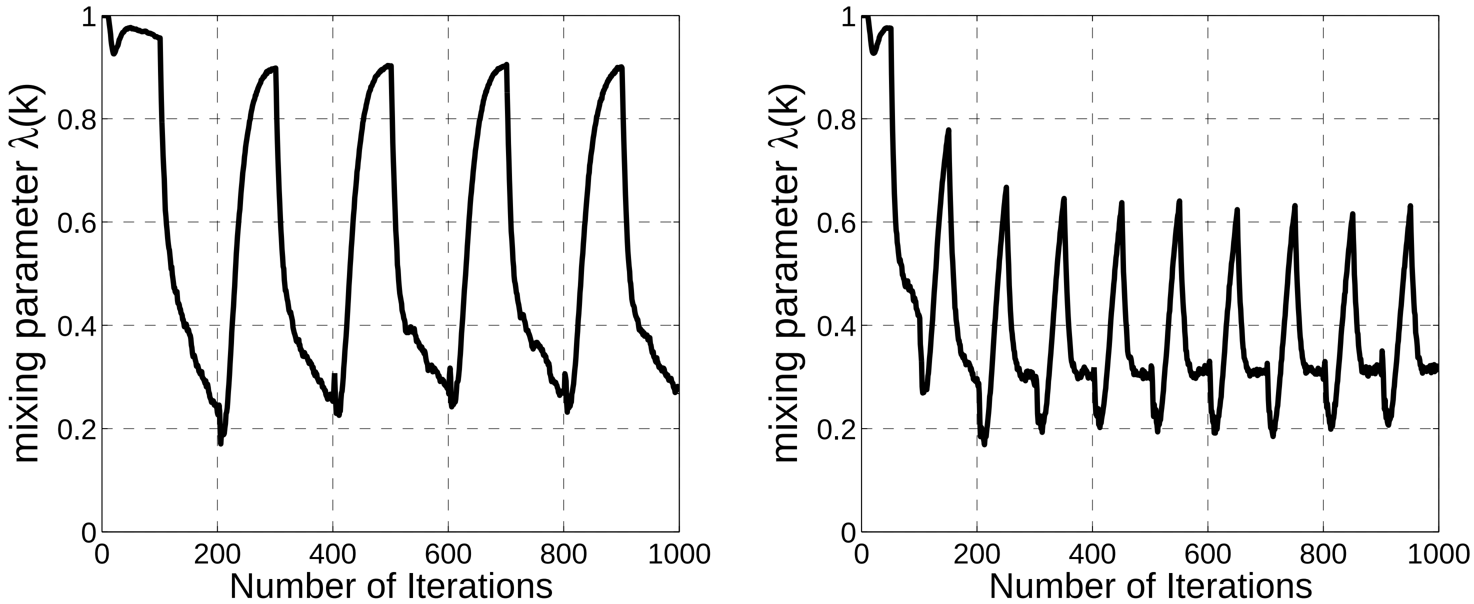


Convexity $\Rightarrow$ existence and uniqueness of solution



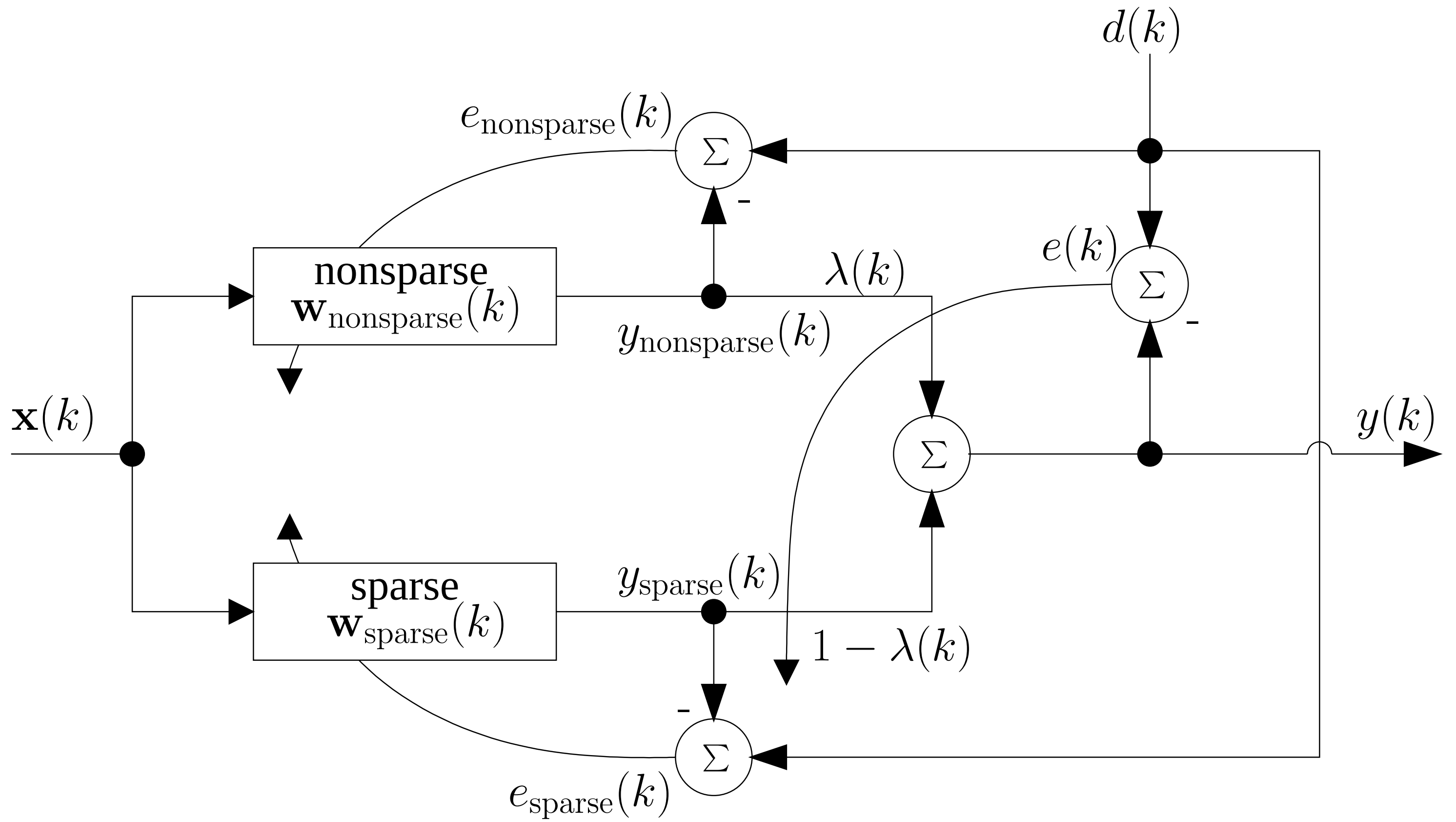
Tracking Capability

The hybrid filter was presented with an input signal which alternated between linear (AR4) and nonlinear (Narendra III) every 100 and every 50 samples



- When alternating every 50 samples a small anomaly in the values of λ occurs immediately following the change in input signal from nonlinear to linear;
- Not an issue for less regular alternations or if there is a more natural progression from "linear" to "nonlinear"

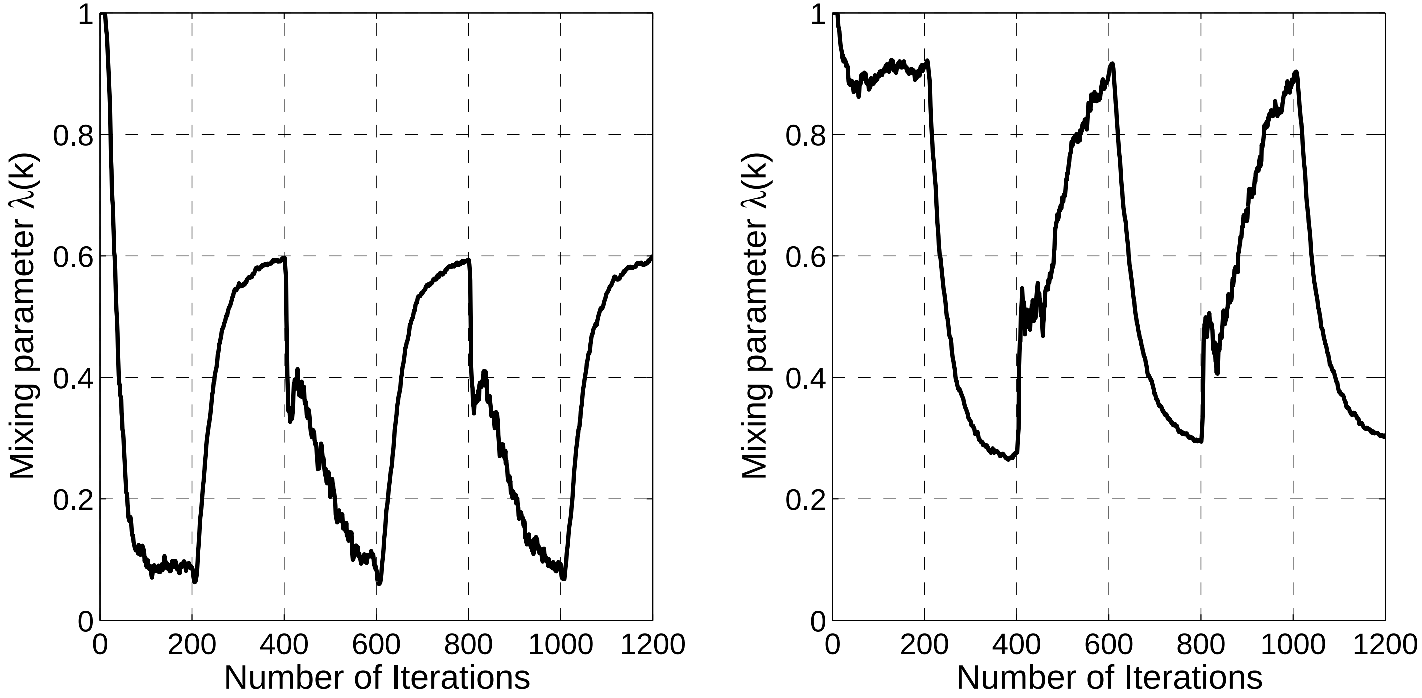
Sparse/Nonsparse Configuration



- For the nonsparse filter the NLMS proved a better choice than the LMS due to its faster convergence speed and improved tracking capabilities
- For the sparse filter the PNLMS and SSLMS were compared

PNLMS in hybrid filter

Not suited for Hybrid Filter



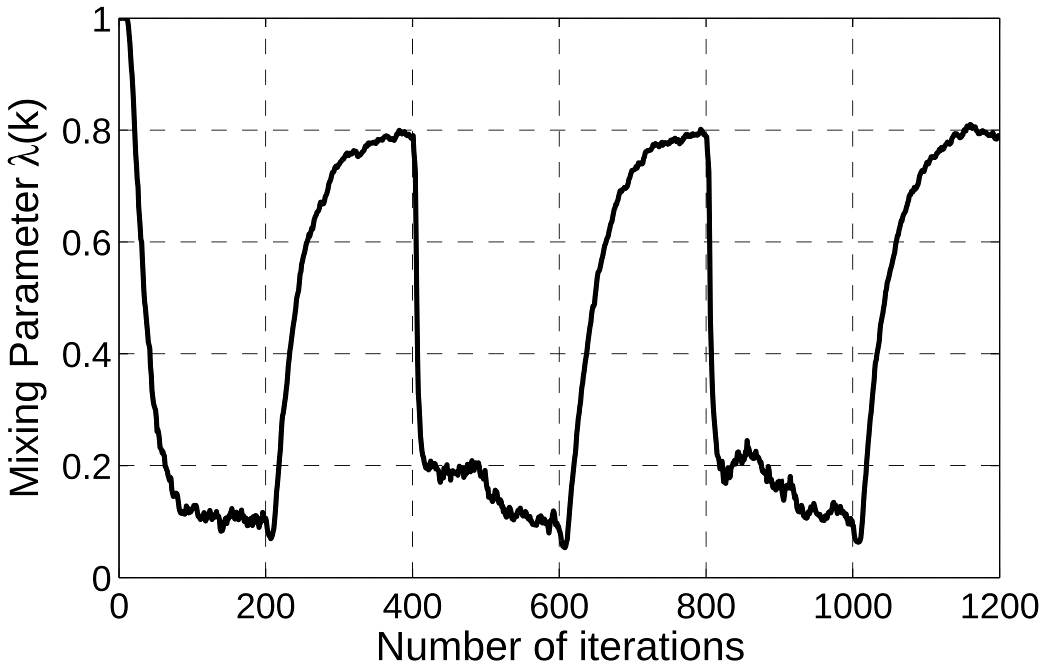
i) Too similar to NLMS

ii) Can span whole range between sparse and nonsparse

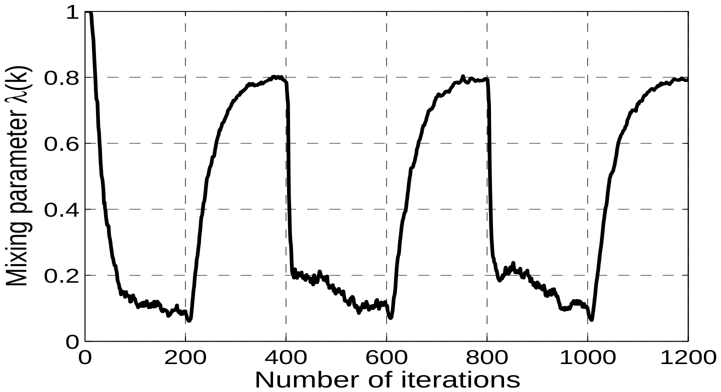
SSLMS in hybrid filter

The same experiment, with PNLMS replaced with SSLMS

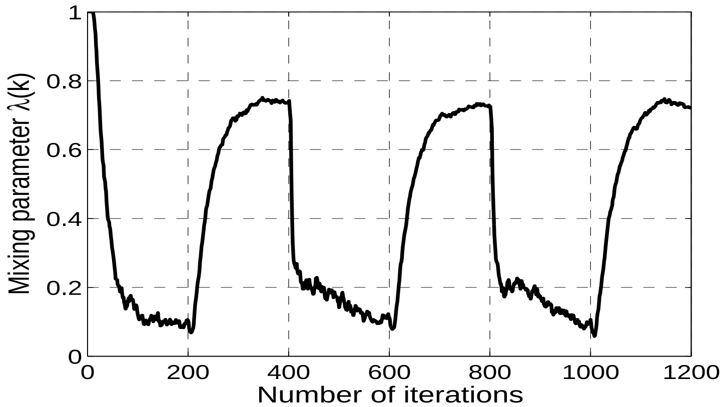
$$
\begin{aligned}
y(k) &= \mathbf{x}^T(k)\mathbf{w}(k) \\
e(k) &= d(k) - y(k) \\
\mathbf{w}(k+1) &= \mathbf{w}(k) + \mu\left(|\mathbf{w}(k)| + \varepsilon\right) e(k)\mathbf{x}(k)
\end{aligned}
$$



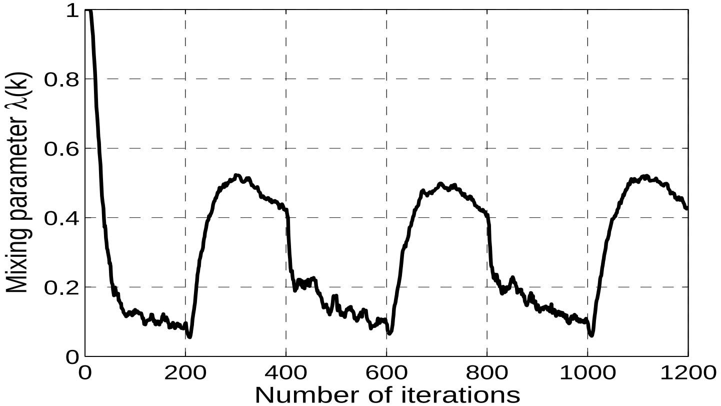
Sparse hybrid with noise



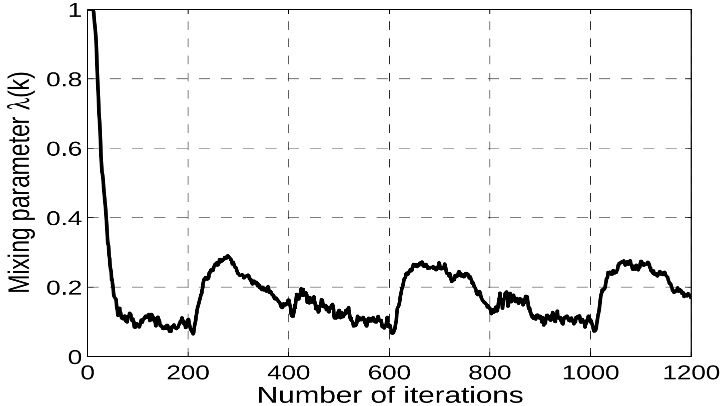
(a) SNR=30dB



(b) SNR=20dB



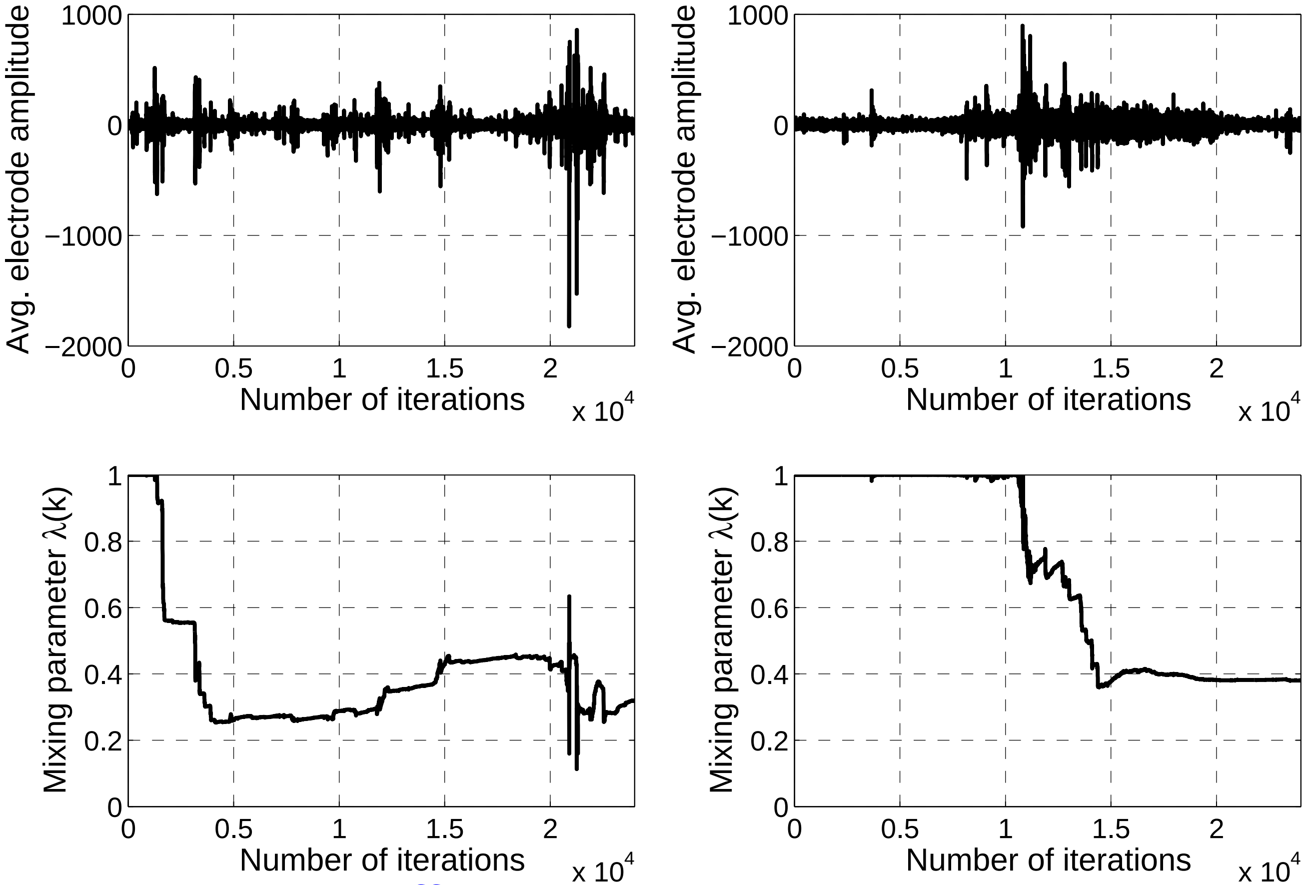
(c) SNR=10dB



(d) SNR=5dB

Real-World Applications:- Epileptic Seizure Data

EEG data showing the onset of epileptic seizures has been observed



The proposed approach effectively detects changes in the nature of the EEG signals

Conclusions

- Novel approach to identify changes in the modality of a signal;
- Convex combination of two adaptive filters for which the transient responses are significantly different, in order to exploit the different performance capabilities of each;
- Collaborative adaptive signal processing approach, based on synergy between the constitutive filters;
- The evolution of the adaptive convex mixing parameter λ, helps determine which filter is more suited to the current input signal dynamics, and thereby gain information about the nature of the signal;
- The analysis and simulations illustrate that there is significant potential for the use of this method for online tracking of some fundamental properties of the input signal.