Efficient Nonlinear Acoustic Echo Cancellation by Dual-stage Multi-channel Kalman Filtering

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Introduction

1. Introduction
   - Application: Single-channel Acoustic Echo Cancellation
     - Example: hands-free call with AEC in mobile phone
   - Problem: Linear AEC cannot compensate nonlinear part of echo
     - Combination of high SPL playback with small and cheap speakers leads to nonlinear distortion
   - Goal: Use Nonlinear Acoustic Echo Cancellation

2. Acquisition of Realistic Echo Signals
   - Evaluation based on simulated nonlinear echo signal not meaningful
   - Construction of realistic smartphone mockup comprising Class D amplifier, smartphone loudspeaker and digital MEMS microphone
   - Simultaneous playback of far-end signal and recording of microphone signal in studio booth (T_{0} = 0.12 s)
   - Scenarios: Mockup on desk (a) and mockup on microphone stand (b)

3. Underlying Digital System Model
   - Odd order power series T{\cdot} of order P with weights w_{k,i}(t) models nonlinear amplifier and loudspeaker with memory of length N_{li}:
     \[ T(x{i}) = \sum_{i=0}^{P} w_{ji}(i) \ast x(2i+1) \]
   - Linear filter h_{li}(i) of length N_{li} >> N_{li} models transmission from loudspeaker to microphone:
     \[ y{i}(t) = h_{li}(i) \ast T(x{i}) \]

4. Dual-stage Multi-channel Kalman Filter
   - Cascaded structure mimics underlying system model
   - Filtering and adaptation is done in short-term Fourier domain
     - Segmentation and reconstruction with overlap-save (not shown)
   - Stage 1: Multi-channel Kalman filter (MCK) [1, 2]
     - Filtered-x multi-channel nonlinear reference \( \hat{X}_{\text{FMC}}(k) \)
     - Complexity reduction by reduced frequency resolution (\( \downarrow D \)), see
   - Stage 2: Single-channel Kalman filter

5. Evaluation on Measured Echo Signals
   - Full-MCK [1]: Reference system with one multi-channel stage
     - Abrupt change of scenario simulated by switching from desk to microphone stand at \( t = 10.5 \) s
   - Proposed DualStage-MCK (\( D = 1 \)) with memory (\( N_{li} = 15 \)) outperforms DualStage-MCK without memory (\( N_{li} = 1 \)) and Full-MCK

6. Complexity Reduction
   - Nonlinear memory is typically short, see
     - \( \hat{w}_{lip}(k) \) are short \( \rightarrow W_{pi}(k) \) are smooth
   - DFT of size \( N \) can be reduced to \( M = M/D \)
     \[ \hat{X}_{\text{FMC}}(\hat{\mu}) = \hat{X}_{\text{FMC}}(\hat{\mu}D) \text{ for } \hat{\mu} = 1, 2, \ldots, M/(2D) - 1 \]
     - Constraining application of complex weights can be omitted [3]

7. Conclusion
   - Novel nonlinear echo canceller with dual-stage structure
     - Speeds up convergence due to short filters with respect to Full-MCK
   - Improves ERLE by modelling a nonlinearity with memory
     - Allows for complexity reduction by reduced frequency resolution
   - Significant improvement of ERLE at only 69% higher complexity than linear only AEC
     - Attractive for real-time speech communication with mobile devices

References