An Efficient Implementation of the Low-Complexity Multi-Coset Sub-Nyquist Wideband Radar Electronic Surveillance

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Electronic Surveillance (ES)

- **Task**: detecting all RF emitters to identify the presence of threats.
- It has a **passive** monitoring system.
- While Radar ES signals are very dense, e.g. can be hundreds of thousands of pulses per second, they have very sparse TF representations.
- ES systems can be noise limited, rather than sparsity limited.
Conventional Radar ES Receivers

- **Instantaneous Frequency Measurements**: limited spectral sensitivity.
- **Rapid Frequency Sweeping** ADC’s: limited temporal sensitivity.
- **Wideband Analog to Digital Converters**: need multi GHz ADC’s.
- **Proposal**: Sub-Nyquist Analog to Information Converter.
Sub-Nyquist Sampling

**Why?**

1. Sampling at the rate of Nyquist is **difficult** or **costly** in some applications, *e.g.* Wideband ADC’s and Wideband Digital Receivers.
2. It is a **waste of resources**, if we sample at a rate, much higher than the information rate.
3. An **application specific** sampling strategy, *i.e.* exploring signal structures.

**How?**

1. Using underlying signal structures, *e.g.* sparsity.
2. Incorporating non-uniform sampling (*random?*) in the sensing framework.
3. Non-linear reconstruction of signals.
Sub-Nyquist Sampling, cont

**Challenges?**
1. *Analog Hardware*: How efficiently can we design the analog part?
2. *Computational Complexity*: How efficient can we implement the non-linear recovery algorithm?
3. *Noise Sensitivity*: Sensitivity to the input noise?
4. *Robustness*: How much the sub-Nyquist algorithm is sensitive to the **signal model mismatch** and **circuit design tolerances**.
Sub-Nyquist Sampling Techniques

Technion Modulated Wideband Convertor Demonstrator

Multi-coset Sampling (Feng&Bresler 1996)
Random Demodulator (Triopp et al. 2007)
Modulated Wideband Convertor (Mishali and Eldar 2010)
Multi-coset Sampling Framework

- **Non-uniform** sampling technique [Feng and Bresler, 1996].
- Sparse multiband signal model.
- A **subspace method** for reconstruction by Feng et al.
- A **convex optimisation** problem for reconstruction by [Mishali and Eldar 2009].
Proposed Sub-Nyquist Sampling Framework

- A Multi-coset sampling strategy.
- Avoiding any complicated operations e.g. SVD, $\ell_1$ minimisation.
- The signal model has to fit into the Radar ES.
Components of Proposed Framework

- A bank of multi-coset channels: it has distinguished delays.
- Digital Fractional Delay (DFD) filters.
- Time-Frequency transform: STFT has currently been used.
- Subband Classifier: Composed of a linear operator (Harmonic Frame), followed by a simple maximum-absolute value operator.
Digital Fractional Delay Implementation

1. $y_1[n]$ → Fractional delay $-c_1T$ → $z_1[n]$ → TF Transform

2. $y_1[n]$ → TF Transform → Fractional delay $-c_1T$

3. $y_1[n]$ → Fractionally delayed TF Transform
Discretisation of Time-Frequency Kernel
Assumptions and Properties

- **Approximate Disjoint Aliased Support**: different to sparsity.

- **No random sampling**: optimal delay parameters from a Harmonic Equiangular Tight Frame (HETF).

- **No DFD filter**: absorption into TF transform.
Evaluation with Radar ES signals

Spectrogram of Clean Signal.

Spectrogram of Noisy Signal,
$\text{SNR} = 29.991\text{dB}$

LoCoMC, using 4 of possible 13 channels.
$\text{SNR} = 33.9789\text{dB}$
Comparison with Other Methods

- Two overlapping ADC’s with 1/6 of Nyquist sampling rate for RFS method.
Comparison with Rapid Frequency Sweeping
LoCoMC at a Glance:

- **Pros:**
  - **Non-iterative:** it may be pipelined.
  - Can use only **a few** Multi-coset channels, *e.g.* as few as \( q = 2 \).
  - Uses a different signal model, *i.e.* **ADAS**, which matches well to some classes of signals, *e.g.* Radar ES.
  - **Large Dynamic Range,** *e.g.* 70 dB, which makes it suitable for the low probability of intercept signals.
  - **Continuously monitoring** wideband RF signals, in a contrast with the rapid frequency sweeping technique.

- **Cons:**
  - Needs a **Fast** “sampler”. The “holder/tracker” can be slow.
  - **Noise folding:** 3 dB processing gain loose per octave. A characteristic of sub-Nyquist sampling techniques.
Noise Folding in Sub-Nyquist Sampling

![Graph showing noise folding in sub-Nyquist sampling](image)

- MC: Solid
- MWC: dashed

Theory: -3 dB per octave

- input SNR = 20 dB
- input SNR = 10 dB
- input SNR = 0 dB
Conclusion and Future Work

**Conclusion:**
- A low SWAP algorithm for Radar ES receiver.
- Exploring parsimonious structure of ES signals.
- When ES signals are ADAS, the signal recovery is guaranteed.
- Outperforms the MUSIC recovery algorithm in the given ES signals.

**Future work:**
- CFAR analysis for parameter selection.
- Pulse descriptor word extraction.
- Sensitivity and robustness analysis.
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