University Defence Research Collaboration (UDRC)
Signal Processing in a Networked Battlespace

E_WP1: Sparse Representations and Compressed Sensing

WP Leader: Mike E. Davies, *University of Edinburgh*
Researcher: Mehrdad Yaghoobi

Abstract: This work package explores low-dimensional signal models for sensing and imaging. Its focus is essentially on the sparsity/compressibility property of most signals, to yield more efficient sensing systems. Although the applications of such models are numerous, the applications which will be initially explored here are wideband RF sub-Nyquist sampling, (3D) Synthetic Aperture Radar, Synthetic Aperture Sonar and LiDAR.

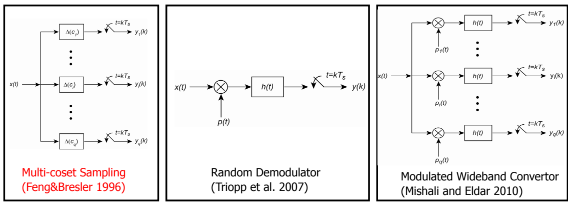
Objective: Sparse representation and compressed sensing techniques are often computationally complex. They are thus not good candidates for many real-world problems. A low Size Weight and Power (SWAP) solution for the mentioned application will be explored in this work package. A fully random structure in sensing and imaging systems, which is an essential component for many compressed sensing techniques, is not easily achievable in most applications. Standard compressed sensing framework will be extended to consider hardware and physical constraints of sensors.

Work Package Structure and Work Plan

- **WP 1.1:** *Efficient Sub-Nyquist Sampling Schemes:*
  - Designing sensing structures.
  - Practical and not complex.
  - Application to wideband electronic surveillance.
- **WP 1.2:** *Compressive Imaging with Sensor Constraints:*
  - Considering the physical constraints.
  - Application to different imaging systems, *e.g.* (3D) SAR.
  - Coherent and adaptive sampling.
- **WP 1.3:** *Compressive Sensing, Beyond Imaging :*
  - Incorporating signal structures.
  - Generic applications, *e.g.* classification, recognition, clustering.
  - Model adaptation and calibration.

WP1.1: Efficient Sub-Nyquist Sampling

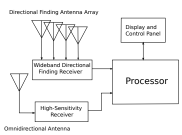
- **Why sub-Nyquist sampling?**
  1. Sampling at the rate of Nyquist: difficult and costly for some applications, *e.g.* Wideband A/D's and Wideband Digital Receivers.
  2. Sampling at a rate higher than information rate, is a waste of resources.
  3. Allows us to have an application specific sampling strategy, *i.e.* exploring signal structures.



- **How?**
  1. Using underlying signal structures, *e.g.* sparsity.
  2. Non-uniform sampling or random sampling.
  3. Non-linear reconstruction of signals.
- **What are the challenges?**
  1. *Analog Hardware:* complexity of the analog design?
  2. *Computational Complexity:* Complexity of non-linear recovery algorithm.
  3. *Noise Sensitivity:* Sensitivity to the input noise.
  4. *Robustness:* To signal model mismatch and circuit design tolerance.

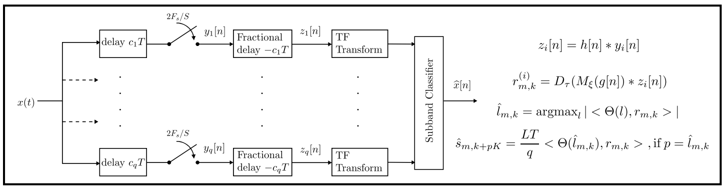
Electronic Support Measures (ESM)

- Detecting all RF emitters to identify presence of threats.
- Instantaneous Frequency Measurements: limited spectral sensitivity.
- Rapid Frequency Sweeping A/D's: limited temporal sensitivity.
- Wideband Analog to Digital Converters: multi GHz A/D's.



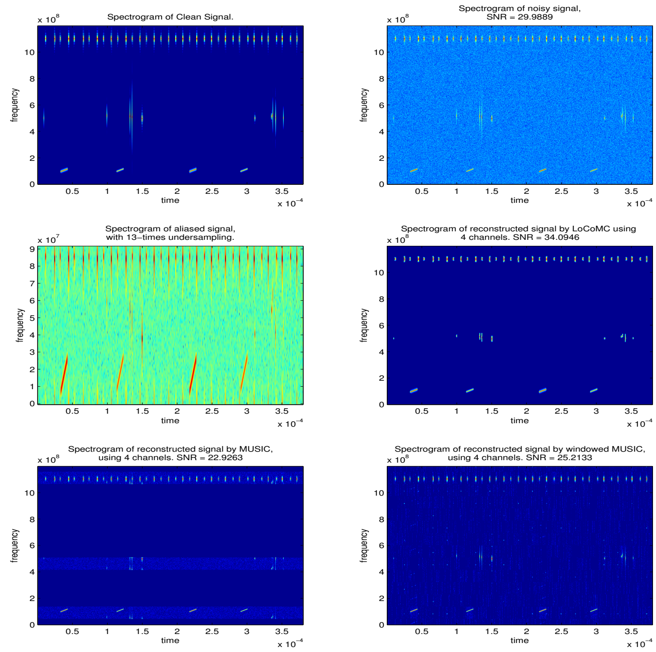
Low-complexity Multicoset Sampling [1]

- *A bank of multicoset channels:* it has distinguished delays.
- *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.



Θ : Harmonic Frame. $\hat{x}[n]$ can be reconstructed using the inverse TF transform.

Evaluation with Radar ESM signals



Advantages of the Proposed Method

- Non-iterative: it may be pipelined.
- Can use only a few multicoset channels, *e.g.* as few as $q = 2$.
- Uses a different signal model, which matches well to some classes of signals, *e.g.* ESM.
- Simple analog hardware (digitiser): periodic non-uniform sampling pattern, which is generally easier to implement than a random sampling pattern.
- 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.

Future Work:

- An optimal TF selection to maximise coherent processing gain.
- Sensitivity and robustness analysis.
- More simulations around about comparisons with canonical methods.

[1] M.Yaghoobi, M. Lexa, F. Millioz and M.E. Davies,"A Low-complexity Sub-Nyquist Sampling System for Wideband Radar ESM Receiver", submitted to ICASSP 2014.

This work was supported by the Engineering and Physical Sciences Research Council (EPSRC) and Dstl.