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

E_WP1: Sparse Representations and Compressed Sensing

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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 and Sonar.

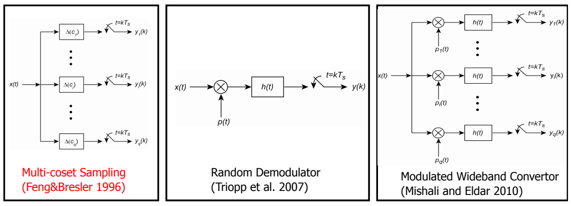
Objective: Sparse representation and compressed sensing techniques are often computationally complex. They are thus not good candidates for many real-world problems. Low Size Weight and Power (SWAP) solutions for the mentioned applications will be explored in this work package. A fully random structure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

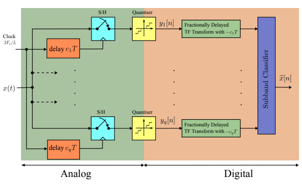
- **Why sub-Nyquist sampling?**
  1. Sampling at the rate of Nyquist: difficult and costly for some applications, *e.g.* Wideband A/D's and Wideband Digital Receivers.
  2. Sampling at a rate higher than information rate, is a waste of resources.
  3. Allows us to have an application specific sampling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



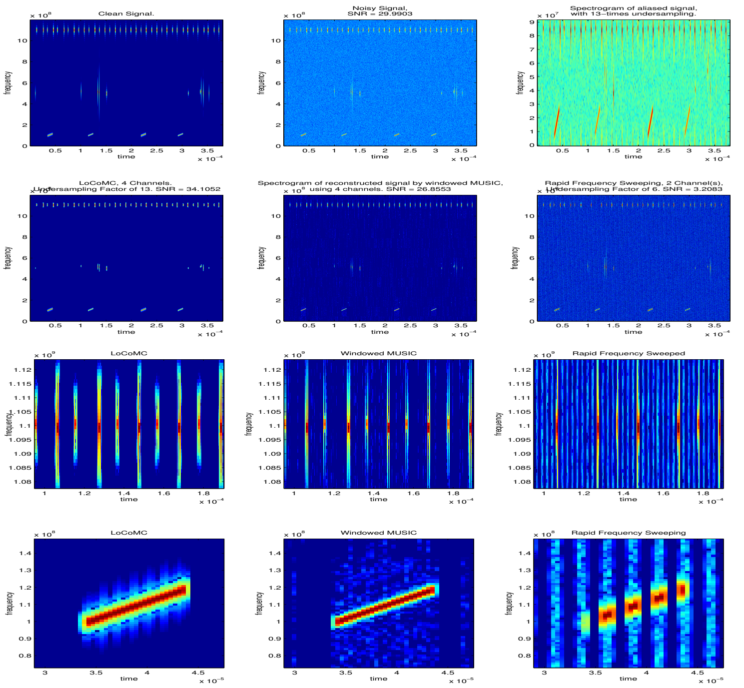
- **How?**
  1. Using underlying signal structures, *e.g.* sparsity.
  2. Non-uniform sampling or random sampling.
  3. Non-linear reconstruction of signals.
- **What are the challenges?**
  1. *Analog Hardware:* complexity of the analog design?
  2. *Computational Complexity:* Complexity of non-linear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

Low-complexity Multicoset Sampling [1]

- ***A bank of multicoset channels:*** it has distinguished delays.
- ***Time-Frequency transform:*** STFT/Chirplet Transform.
- ***Subband Classifier:*** composed of a linear operator, followed by a simple maximum-absolute value operator.



Evaluation with Radar ESM signals

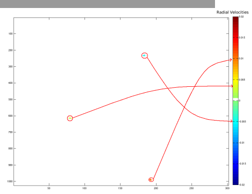


Advantages of the Proposed Method

- Non-iterative: it may be pipelined.
- Can use only a few multicoset channels, *e.g.* as few as $q = 2$.
- 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.

WP1.2: Compressive Imaging with Sensor Constraints

- ***Fast LF 3D SAR:*** spatial sparsity of 3D SAR.
- ***Multi-channel GMTI SAR:*** phase difference between channels for velocity estimation. Few moving targets → sparsity of the velocity vector.
- ***Sub-Nyquist Intercept Sonar:*** a small array of sensors.



SAR GMTI using ℓ_1 recovery.

Future Work:

- Incorporating a similar low-complexity CS technique to other applications, *e.g.* intercept sonar, beam forming.
- Adaptation of the proposed sub-Nyquist technique to the channelised ESM receivers.
- Compressive/off-the-grid SAR GMTI and 3D SAR.

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

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