[O10] Synthetic Aperture Radar Processing with Zeroes

Theme: Detection, Localisation & Tracking

PI: Mike Davies, University of Edinburgh

Researcher: Shaun I. Kelly

Introduction:

Synthetic Aperture Radar (SAR) provides the military with an extremely valuable means of remote imaging and plays an important role in target detection. SAR measures the electromagnetic signal reflections from a target region to generate an image. The processing of raw received data to generate an image is usually performed using linear methods. However when there is missing data, e.g. spatially or spectrally notches, the performance of such reconstruction algorithms deteriorates considerably. This project aims to provide non-linear methods to improve image reconstruction performance when there is missing data.

UWB SAR

In a VHF/UHF SAR systems the radar band will contain frequencies where there is interference or transmission is not allowed. Spectral notches are added to the transmitter and/or the receiver to avoid this interference.

Counter SAR Jamming

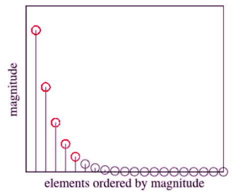
Using an active antenna which is a 2-D array of many transmit/receive elements, in principle, it is possible to phase the signals transmitted and received by the elements in order to dynamically change the beam pattern. Hence, notches could be placed in the beam pattern in both azimuth and range in order to attenuate the reception of signals emitted from a set of specific points in the scene.

Sparsity

A vector $\mathbf{x}$ is K-sparse, if only K of its elements are non-zero.

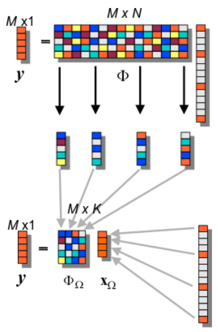
$$[0, 0.5, 0, 0, 0.1, 0, -0.2, 0, 0, 0, 0]^T$$

In the real world "exact" sparseness is uncommon, however, many signals are "approximately" K-sparse. That is, there is a K-sparse vector $\mathbf{x}_K$, such that the error $\|\mathbf{x} - \mathbf{x}_K\|_2$ is small.



Measurement Systems

Sparsity allows us to convert an under-determined problem into an over-determined one.



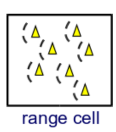
Reconstruction Algorithms

A practical solution is the convex program, ℓ_1-norm relaxation (Basic Pursuit DeNoising):

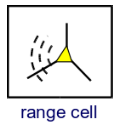
$$\hat{\mathbf{x}} = \min_{\mathbf{x}} \|\mathbf{x}\|_1 \quad \text{s.t.} \quad \|\mathbf{y} - \mathbf{\Phi x}\|_2 \le \epsilon$$

Speckle

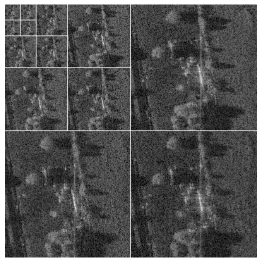
SAR images composed of two main components:



1. Speckle due to many random reflectors - *not compressible*



2. Coherent reflectors (often targets of interest) - *compressible in spatial domain*



Wavelet Decomposition of a SAR image

Fast Operators

Sparse reconstruction algorithms require computationally efficient algorithms for $\mathbf{\Phi}$ and $\mathbf{\Phi}^H$. We have proposed algorithms based on "fast back-projection" methods.

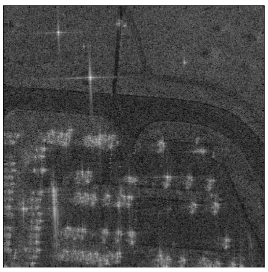
Calibration

Correct phase errors, which are a result of the estimate of the propagation delay to the scene centre.

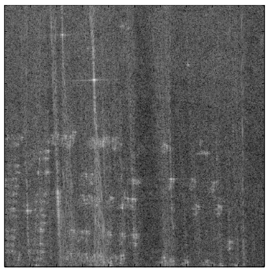
$$\{\hat{\mathbf{x}}, \hat{\boldsymbol{\theta}}\} = \min_{\{\mathbf{x},\boldsymbol{\theta}\}} \|\mathbf{x}\|_1 \quad \text{s.t.} \quad \|\mathbf{y} - \text{diag}\{e^{i\boldsymbol{\theta}}\}\mathbf{\Phi x}\|_2 \le \epsilon$$

i.e. minimise w.r.t both $\mathbf{x}$ and $\boldsymbol{\theta}$.

Example: 50% Nyquist

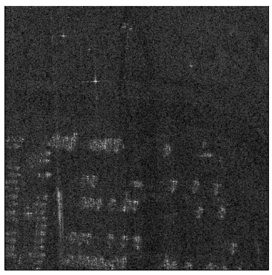


fully sampled image



back-projection

sparse CS



mixed ℓ_1/ℓ_2

A mixed ℓ_1/ℓ_2 solution:

$$\mathbf{x}^\star = \min_{\mathbf{x}} \|\mathbf{x}\|_1 \quad \text{s.t.} \quad \|\mathbf{y} - \mathbf{\Phi x}\|_2 \le \epsilon$$

$$\hat{\mathbf{x}} = \mathbf{x}^\star + \mathbf{\Phi}^\dagger(\mathbf{y} - \mathbf{\Phi x}^\star)$$

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