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Adaptive Frequency Allocation in Radar Imaging: Towards Cognitive SAR

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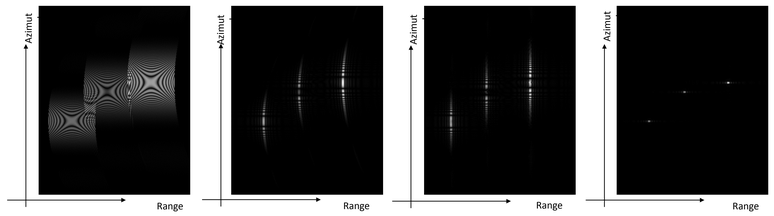
Contributions

- A framework for **adaptive transmission and reception of SAR signals** in the frequency domain according to the behavior of the spectrum.
  - **Exploiting** existing Sub-Nyquist methods based on **Xampling** and **Compressive Sensing.**
  - Paving the way to cognitive SAR [1].
- **Improving signal-to-noise** ratio in SAR platforms by concentrating the power of the transmitted signal in narrow bands rather than over a wide spectral band.

Frequency Adaptive Receiver

- The proposed receiver reconstructs the SAR images using **Sub-Nyquist sampling** rates at the receiver.
  - The sub-sampled frequency bands can be dynamically change between the different scenes capturing.

Our receiver processes the returned signals using the algorithm proposed in [2] which relies on Fourier Range-Doppler Algorithm and exploits sparsity in order to reconstruct the scene using less samples than the required by Nyquist. The stages of Fourier domain RDA are described below:



Raw data → Range Compression → Fourier RCMC → Azimuth Compression

Frequency Adaptive Transmitter

- We propose to enable dynamic spectrum changes of the transmitted SAR waveform . The energy of the signal is concentrated only at the receiver sampled bands in the sub-Nyquist receiver:

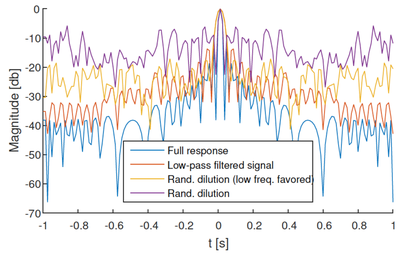
$$\tilde{H}(\omega,t)=\begin{cases}H(\omega) & \omega\in\mathcal{N}_b(t)\\ 0 & \text{otherwise,}\end{cases}$$

where $H(\omega)$ is the original transmitted signal in the Fourier domain and $\mathcal{N}_b(t)$ is the support of the bands during time.

- The transmitted signal has no affect on the sub-Nyquist receiver.

Coefficients Selection

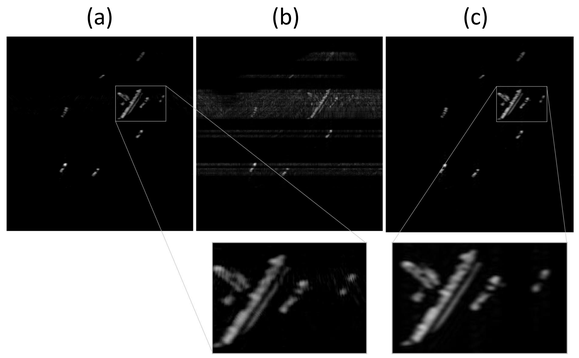
- Choosing the subset of Fourier coefficients within the entire Nyquist bandwidth set is governed by theoretical trade-offs and practical limitations.



Coefficients selection	Main lobe width	Side-lobe level
Full Response	4	-13 dB
Low-pass	8	-13 dB
Random dilution (low freq)	8	-14 dB
Random dilution	4	-7 dB

- One-dimenssional Chirp signal autocorrealtion for various selection of subsampling strategy (subsampling in the Fourier domain).

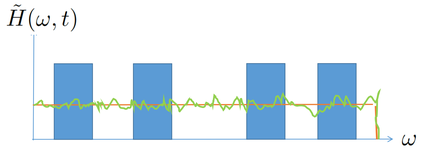
- Sparse Reconstruction of a 2D scene using 25% of the Nyquist required sampling rate. (a) our algorithm with random selection. (b) Conventional RDA. (c) Reference image.



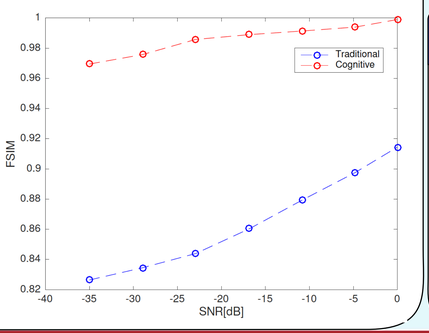
Random frequency bands selection best copes with the trade off between theoretical and practical sampling limitations and encourage dynamic changes.

Signal-to-Noise performance

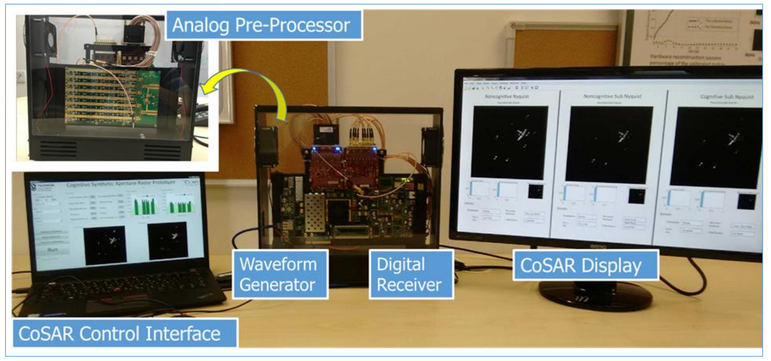
- The energy of the transmitted signal is concentrated only in the transmitted bands resulting in better SNR in the relevant frequency bands [3].



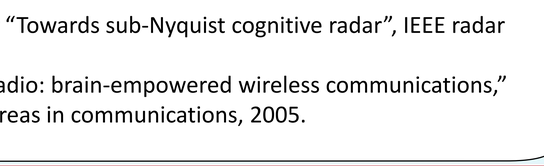
- Comparison between traditional (blue) and cognitive SAR (red) system performance in a noisy environment. The resulting images in each case are compared to the reference scene using the FSIM index.



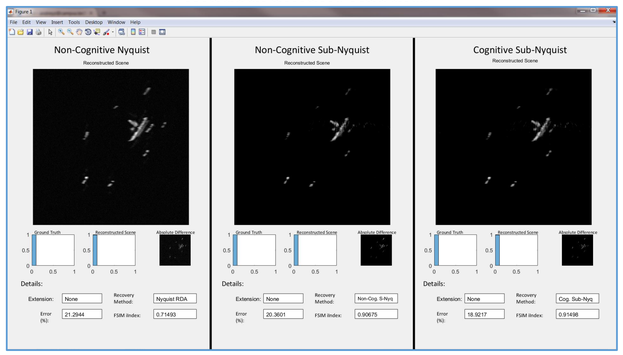
Hardware Prototype



- 5 MHz cognitive chirp
- 4 subbands of 625 kHz bandwidth
- Xampling at 1/4th of the Nyquist rate
- RCMC at 1/8th of the Nyquist rate



Measurement Results



References

[1] K. Aberman and Y. C. Eldar, “Sub-Nyquist SAR via Fourier Domain Range-Doppler Processing”, IEEE Transactions on Remote Sensing and Geoscience, 2017.
[2] D. Cohen and Y.C Eldar “Towards sub-Nyquist cognitive radar”, IEEE radar conference,” 2016
[3] S. Haykin, “Cognitive radio: brain-empowered wireless communications,” IEEE journal on selected areas in communications, 2005.