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Sub-Nyquist MIMO Radar Prototype With Doppler Processing

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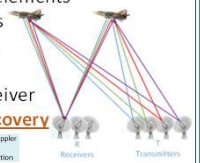
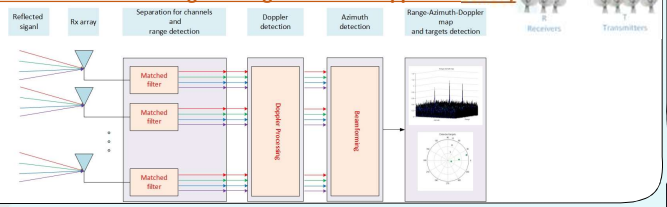
Contributions

- Prototype realizes both spatial and temporal sub-Nyquist sampling in a MIMO radar without loss of angular and range resolution
- Sub-Nyquist 4x5 MIMO array shows same detection performance as Nyquist 8x10 ULA
- Cognitive transmission is employed to further enhance SNR for sub-Nyquist arrays

Collocated MIMO Radar

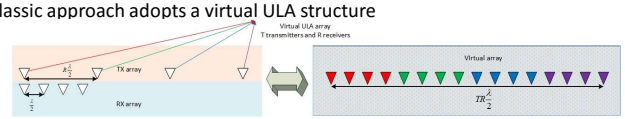
- MIMO combines multiple transmit and receiver antenna elements
- Each transmitting element radiates orthogonal waveforms
- **Core idea:** achieving high spatial resolution by separation and coherent processing of the receivers' channels
- All space is uniformly lit - beamforming is done at the receiver
- Conventional Processing for Range-Azimuth-Doppler Recovery





Proposed Array Structure and Signal Model

- Classic approach adopts a virtual ULA structure

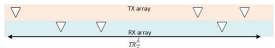


Sub-Nyquist in Space

Problem: High azimuth resolution → Large aperture → Large number of elements

Solution:

- Preserving azimuth resolution of T transmitters and R receivers while using M<T transmitters and Q<R receivers
- Elements are randomly located with uniform distribution across the virtual ULA's aperture of T transmitters and R receivers

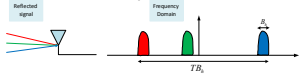


Sub-Nyquist in Time

Problem: High range resolution → Large signal bandwidth → High sampling rate

Solution:

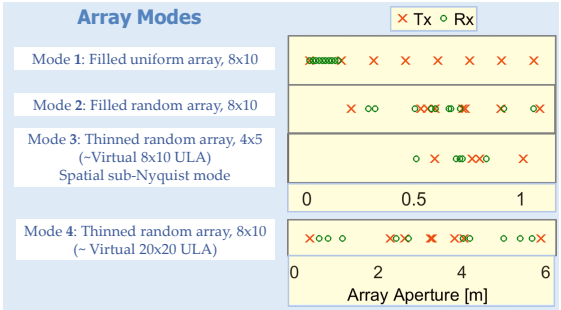
- Preserving range resolution of signal with bandwidth TB_h while the effective sampling rate is lower
- The transmissions are performed over total bandwidth TB_h.

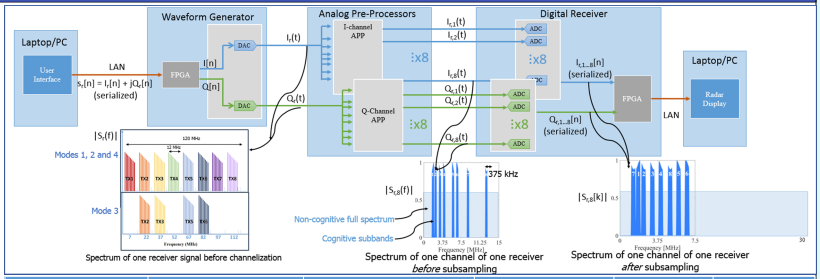


- For each transmission, sub-Nyquist sampling scheme is applied

Prototype Overview

Array Modes

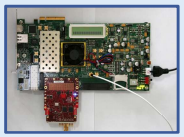




	BW per Tx (incl. guard-bands)	BW per Tx (excl. guard-bands)	Temporal sampling rate	Spatial sampling	# Tx/Rx channels
Nyquist (Mode 1)	15 MHz	12 Mhz	30 MHz	8x10	80
Sub-Nyquist (Mode 3)	3 MHz	3 MHz	7.5 MHz	4x5	20
Reduction	80%	75%	75%	50%	25%

Waveform Generator

- Total BW, 8 Tx: 120 MHz 3 MHz guard-bands
- Eight 375 kHz cognitive slices per Tx
- Cognitive BW, 1 Tx: 3 MHz (= 8 x 375 kHz)
- BW reduction, 1 Tx 75% (3 of 12 Mhz)

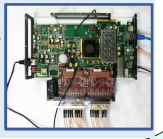


Analog Pre-Processor

- APP filters the receiver data into eight channels
- Mitigate subsampling noise

Digital Receiver

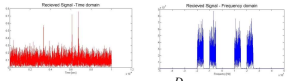
- Two 16-bit eight-channel digitizers
- Sub-Nyquist sampling rate: 7.5 MHz/channel
- Signal BW with guard-bands: 30 MHz/channel



Xampling in Time and Space and Doppler Focusing

- Received signal at the qth antenna after demodulation:

$$x_q(t)=\sum_{p=0}^{P-1}\sum_{m=0}^{M-1}\sum_{l=1}^{L}h_m\left(t-p\tau-\tau_l\right)e^{j2\pi\beta_{mq}\vartheta_l}e^{j2\pi f_l^D pT}$$

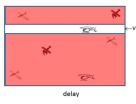


- **Goal:** estimate the targets range azimuth and Doppler $\tau_l, \vartheta_l, f_l^D$.
- Fourier coefficients :

$$y_{m,q}^{p}[k]=\sum_{l=1}^{L}\alpha_l e^{j2\pi\beta_{mq}\vartheta_l}e^{-j\frac{2\pi}{\tau}k\tau_l}e^{-j2\pi f_m\tau_l}e^{j2\pi f_l^D pT}$$

Fourier coefficients of the channel between mth transmitter and qth receiver for the pth pulse — governed by the elements location — governed by the carriers frequencies

- Xampling: obtain set of Fourier coefficients from low rate samples
- Doppler Focusing: Doppler processing in the Fourier domain



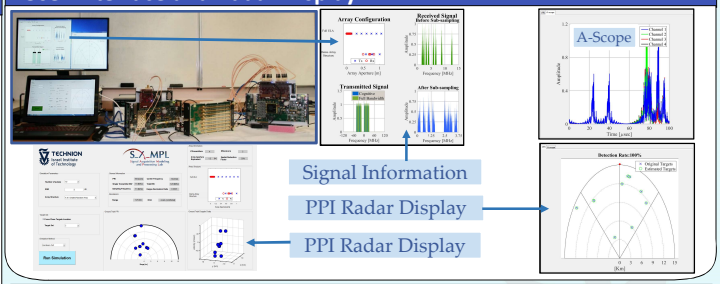
- Fourier coefficients for the mth transmission in matrix form

$$\mathbf{Z}^m=\left(\bar{\mathbf{B}}^m\otimes\mathbf{A}^m\right)\mathbf{X}_D\mathbf{F}^H$$

Azimuth dictionary — Range dictionary — Sparse matrix whose elements are located at the targets' range-azimuth-Doppler. — Doppler dictionary

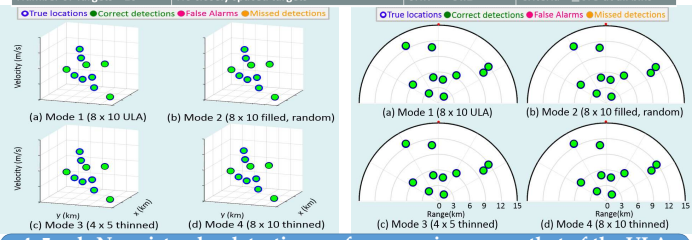
Random Array → FDM Transmissions → XAMPLING → $\min\|\mathbf{X}\|_0$ $s.t.\ \mathbf{Z}^m=\left(\bar{\mathbf{B}}^m\otimes\mathbf{A}^m\right)\mathbf{X}_D\mathbf{F}^H$ $0\le m\le M-1$ → Proposed Algorithm for Simultaneous Sparse 3D recovery

User Interface and Radar Display



Sample Measurement Results

Number of Targets – 10	No closely spaced targets	SNR = $-8dB$	Criteria – ± 0.5 at all bins



4x5 sub-Nyquist radar detection performance is same as that of the ULA