MPAR Data Processing and Data Management

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MPAR Capabilities Drive Complexity of Data

- Phased array radar data management and signal processing requirements are driven by:
  - Bandwidth of the data interface from the radar front end (antenna or receiver)
  - Signal processing algorithms used
  - Latency of signal processing (required throughput rate)

- The radar architecture and mission requirements drive all three concerns above:
  - Multiple-simultaneous beams
  - Dual polarization
  - Air surveillance and weather surveillance

**Dual-polarization and Multiple Simultaneous Beams Present a Data Interface, management, and Processing Throughput Challenge for MPAR**
For this exercise, we consider data management to consist of the tasks between radar beamforming and dissemination of measurement products and spectral moments (weather data) and surveillance information.

For each radar beam that is simultaneously received, we digitally sample the returns and generate Inphase and Quadrature samples.

\[ A_c \cos(2\pi f_c t + \phi) \]

\[ M \leq \phi \]

\[ I(t) = M(t) \cos(\phi(t)) \]

\[ Q(t) = M(t) \sin(\phi(t)) \]
Sampling of RF (radio frequency) or IF (intermediate frequency) signals into I/Q digital samples

- Can be done on array (digital array radar)
- Can be done in beamforming network (digital beamformed array)
- Can be done in radar receiver (active or passive phased array with RF beamforming)
Data Management - Sampling and Throughput

- Amount of I/Q data from the radar front end – an example
  - Two polarization channels (horizontal and vertical)
  - Pulse compressed waveform (10 MHz)
  - Digital sampling of 50 MHz IF at 60 MS/sec (super-Nyquist)
  - 16 bit analog to digital converter on I and Q

- 2 polarization channels X 60 Msamples/second X 4 bytes (I and Q)
  - 480 MB/sec per beam – each additional simultaneously formed receive beam increases the total bandwidth
  - Raw I/Q samples will be downsampled and/or averaged in range to reduce bandwidth requirements of the signal processing chain
  - Data interfaces between the radar array (or receiver) and the signal processors will need to be wideband
Suppose we had radar return data (IQ samples) with multiple parameters (pulses, range bins, and frequency/polarization channels).

The format of the index into the cube is \((m,n,p)\) where \(m\) is the row, \(n\) is the column, and \(p\) is the layer.

- Each row represents one pulse of radar I/Q data (the \(m\) index).
- Each column represents a range bin of radar I/Q data (the \(n\) index).
- Each layer represents one channel of radar I/Q data (the \(p\) index).
“Partially-parallel” processing chains
- Same raw I/Q radar data input and intermediate products, but some processing for air surveillance is incompatible with weather processing (Moving Target Indicator filtering, for example)

Latency of Weather Processing vs. Air Surveillance Processing
- Air surveillance requires ‘real-time’ processing / Weather can be less time critical
  - Real-time: For a 1ms PRI (1000 Hz PRF) 8 pulse sequence, all processing would need to be completed in 8ms
- Active Track (Phase Arrays) versus Track While Scan (spinning radars)
  - Active track – slower volume scans with faster interleaved dedicated track dwells (radar must close track loop between track dwells) but may have 10’s of seconds for full volume scan
  - Track While Scan – target positions are updated on each revolution (scan) of the antenna, fast volume scan times (e.g. 4 seconds)
"Partially-parallel" processing chains
Sample Signal Processing Flow

I/O Processor → Beam Processor → Beam Processor

Weather Volume Processor → Data Distribute

High-speed Digital → GigE

Quad-core CPU

Backend Processing
Signal Processing Impacts of Phase Coding

- Phase Coded Waveforms – Sidelobes in Range ‘Flood’ Adjacent Range Intervals
Range Sidelobes Example

- Time Sidelobes Smear Data ... Distort Features
- Distortion Will Degrade Hazardous Weather Detection Algorithms

![Graph showing reflectivity vs. range with labels for red and blue data sets. Red: Measured Precipitation Data from SPS-48 WEC. Blue: Data Smeread with Coded Waveform Point Spread Function.](image-url)
Clutter Filtering Challenges

- Pulse Sequence in PAR is Not Continuous
  - One Burst of Pulses Each Azimuth
  - Clutter Filters Have Limited Length Sequence on Which to Operate

- Traditional Filters (TDWR, NEXRAD) Require Certain Number of Pulses to ‘Charge’ Filter
  - TDWR & NEXRAD are Continuously Scanned … Once Charged, Do Not Need to be Charged Again

- Use of Traditional Filters Will Degrade Measurements:
  - Either More ‘Lost’ Data Resulting in Increase in Error for Reflectivity, Mean Radial Velocity, and Spectrum Width OR
  - Less ‘Lost’ Data Resulting in More Contamination to Spectral Moment Measurements from Filter Transient

NEXRAD & TDWR Clutter Filtering Not Appropriate for PAR
Clutter Filtering Challenges

Clutter Filter Bias Example

Blue: Spectrum of Weather Before Clutter Filtering

Red: Spectrum of Weather After Filtering
- Wide Clutter Notch, Maximum Distortion

Green: Spectrum of Weather After Filtering
- Narrow Clutter Notch, Moderate Distortion

Narrow & Steep Clutter Notch Reduces Distortion of Weather Spectrum
Clutter Filtering - Previous Solutions

- Finite Impulse Response (FIR) Filters:
  - Advantages: Finite Number of ‘Lost’ Data During Charging
  - Disadvantages: Cannot Achieve Required Clutter Rejection (with Acceptable Bias) with Reasonable Number of Pulses, Typically Amount of ‘Lost’ Data Not Acceptable

- Infinite Impulse Response (IIR) Filters:
  - Advantages: Good Clutter Rejection, Well Tested (NEXRAD, TDWR)
  - Disadvantages: Varying (Non-deterministic) Amount of ‘Lost’ Data During Charging, Typically Amount of ‘Lost’ Data Not Acceptable

- Covariance Matrix Based Filters:
  - Advantages: No Data Lost … Given N Pulses, All N Pulses Available to Estimate Reflectivity, Velocity, and Spectrum Width
  - Disadvantages: To Date, Weather Measurement Errors (Reflectivity, Mean Radial Velocity, Spectrum Width Bias) Desired in TDWR Spec for Ground Clutter Filtering Not Met (Limitations Similar to FIR Filters)