Polarimetric L-Band Imaging Scatterometer Data Processing

Heath Yardley
University of Adelaide
Radar Research Centre
Overview

- Radar Parameters
- Imaging Geometry
- Imaging Algorithm
- Gamma Remote Sensing
  - Modular SAR Processor (MSP)
  - Motion Compensation (MoCom)
- Calibration
  - Polarimetric Active Radar Calibrators (PARCs)
  - Triangular trihedrals
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1.26GHz</td>
</tr>
<tr>
<td>Power</td>
<td>25W</td>
</tr>
<tr>
<td>Maximum Duty Cycle</td>
<td>4%</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>30MHz</td>
</tr>
<tr>
<td>Pulse Length</td>
<td>100ns-10us</td>
</tr>
<tr>
<td>Pulse Repetition Frequency Maximum</td>
<td>20kHz</td>
</tr>
<tr>
<td>Transmit Polarisation</td>
<td>Interleaved H/V</td>
</tr>
<tr>
<td>Receive Polarisation</td>
<td>Simultaneous H/V</td>
</tr>
<tr>
<td>Look Direction</td>
<td>Interleaved L/R</td>
</tr>
<tr>
<td>Antenna Type / Gain</td>
<td>2x2 Patch Array / 9dBi</td>
</tr>
</tbody>
</table>
Imaging Geometry

- Height = 50m 110m
- Height = 200m 440m
- Height = 3000m 2200m
Range-Doppler Imaging Algorithm

- Good Accuracy
- Efficiency gained by using the Fast Fourier Transform
- Assumes two independent dimensions (Range-Doppler)
- Processes Range Dimension with a matched filter using Fast Convolution
- Processes Azimuth Dimension with a matched filter in Doppler domain

Flowchart:
- Raw Data
  - Range Compression
    - Azimuth FFT
      - RCMC
        - Azimuth Compression
          - Azimuth IFFT
            - Image Product
Range-Doppler Imaging Algorithm

- Matched Filter using Fast Convolution in range dimension
  \[ s_{rc}(\tau, \eta) = IFFT\{FFT\{s_{raw}(\tau, \eta)\} \times G(f_\tau)\} \]

- G is a filter matched to the transmit waveform usually with a window function applied

- FFT/IFFT are forward and reverse fast Fourier transforms

- \( \tau \) is range time

- \( \eta \) is azimuth time
Range-Doppler Imaging Algorithm

- Raw Data
- Range Compression
- Azimuth FFT
- RCMC
- Azimuth Compression
- Azimuth IFFT
- Image Product

Take Azimuth Fast Fourier Transform

\[ s_{rd}(\tau, f_\eta) = \text{FFT}_\eta\{s_{rd}(\tau, \eta)\} \]

Allows for block processing
Range-Doppler Imaging Algorithm

- Interpolate in range for each azimuth frequency

\[ R_{rd}(f_\eta) = \frac{R_o}{D(f_\eta, V_r)} \]

\[ D(f_\eta, V_r) = \sqrt{1 - \frac{\lambda^2 f_\eta^2}{4V_r^2}} \]

- \( \lambda \) is radar wavelength
- \( V_r \) is platform speed
- \( R_o \) is imaging range
- Usually use truncated Sinc function interpolation
- Sinc length 8-16
Range-Doppler Imaging Algorithm

- Matched filter in the azimuth dimension for each range

\[ H_{\text{az}}(f_\eta) = \exp \left\{ j \frac{4\pi R_0 D(f_\eta V_r) f_o}{c} \right\} \]

- \( f_o \) is the radar frequency
- \( c \) is the speed of light
- Notice the filter changes for each range, \( R \)
- Dependence on platform dynamics
Range-Doppler Imaging Algorithm

- Complete processing with an azimuth inverse fast Fourier transform

\[ s_{slc}(\tau, \eta) = \text{IFFT}_\eta\{S_{rd}(\tau, f_\eta)\} \]

- Repeat process along the range compressed data sequence
Modular SAR Processor (MSP)
- Implements the Range-Doppler Algorithm
- Each processing stage is executed on an intermediate binary file with an associated parameter file
- All polarisation combinations and look directions are processed separately

Image Products
- Single Look Complex (SLC) – 32bit floating point
- Multi Look Intensity (MLI) – 32bit floating point
- Scaled raster – 8bit integer
Gamma RS – SMAPex 1

\[ dR = 6.0m \]
\[ dAz = 4.2m \]
Gamma RS – SMAPEX 1

Right Side VV

Right Side HH

\[ dR = 6.0m \]
\[ dAz = 4.2m \]

Right Side VH

Right Side HV
Gamma Remote Sensing

- Motion Compensation (MoCom)
  - Interpolates the range compressed data using navigation information from the platform
  - Corrects for deviations from the reference platform track
  - Corrects for mismatches in the data compared to that expected by the azimuth matched filter
  - Sharpens the image focus

\[ dR = 6.0m \]
\[ dAz = 4.2m \]
SAR Calibration

- Scattering Matrix - $S$
- System model (receiver voltage) - $L$
- Variables $\psi_t, \psi_r$ are relative phase inside a range cell
- N is complex additive white Gaussian noise
- Cross talk terms - $\delta_1, \delta_2, \delta_3, \delta_4$
- Channel imbalance - $f_1, f_2$
- Amplitude factors due to range to target and back as well as antenna pattern asymmetry - $A_r, A_t$
- Need to estimate scattering calibration matrix parameters
- This formulation includes cross coupling between the various polarisation combinations due to antenna imperfections and system leakage

$$S = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$

$$L = \begin{bmatrix} Z_{hh} & Z_{hv} \\ Z_{vh} & Z_{vv} \end{bmatrix} = R^HST + N$$

$$R = A_re^{j\psi_r} \begin{bmatrix} 1 & \delta_2 \\ \delta_1 & f_1 \end{bmatrix}$$

$$T = A_te^{j\psi_t} \begin{bmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{bmatrix}$$
Calibration – Point Targets

- Polarimetric Active Radar Calibrators (PARCs)
  - Fixed known Radar Cross Section - $A_1, A_2, A_3$
  - Combination of three gives response in all polarisation combinations
  - Direct method for scattering calibration matrix parameters although not as simple as it appears

\[ A_i = G_e \frac{G_A^2 \lambda^2}{4\pi}, i = 1,2,3 \]
\[ S_1 = A_1 \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} \]
\[ S_2 = A_2 \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \]
\[ S_3 = A_3 \begin{bmatrix} -1 & -1 \\ 1 & 1 \end{bmatrix} \]
Calibration – Point Targets

- Triangular Trihedral
  - Fixed known Radar Cross Section
  - Gives response in co-polarised channels only
  - Direct method for scattering calibration matrix parameters also non trivial

\[
A_T = \frac{4\pi a^3}{3\lambda^2}
\]

\[
S_T = A_T \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}
\]
Calibration – Image Example

\[ dR = 6.0\,m \]
\[ dAz = 4.2\,m \]
Summary

- Range-Doppler imaging algorithm focuses raw radar data
- Gamma RS is proprietary modular software implementing the range-Doppler algorithm
- Motion compensation must be applied for sharp imagery
- Calibration is a non-trivial stage in producing useful backscatter measurements