Synthetic Aperture Radar Modeling using MATLAB and Simulink

Naivedya Mishra
Team Lead
Uurmi Systems Pvt. Ltd. Hyderabad
Agenda

• What is Synthetic Aperture Radar?
  • SAR Imaging Process
• Challenges in Design and Simulation
• Modeling in MATLAB
• System Block Diagram
• Algorithm Flow
• Modeling in Simulink
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• Conversion Simulink-HDL
  • Major modules involved
• SimRF Model for Raw Data Generation
• Results and Discussions
  • Simulator GUI Snapshots
  • Other Results
What is Synthetic Aperture Radar? (Contd.)

• Synthetic Aperture Radar (SAR) is application of RADAR system to generate a ‘Synthetic Aperture’

• Generating High Resolution Images out of Radar data.

• Exploiting the capabilities of Radar Ranging by moving the platform orthogonal to antenna radiation direction.
  
  • Radio-waves transmitted by the antenna are scattered, received back, recorded, and processed to generate images of the ground terrain-objects.
  • Two-dimensional data is collected by using such a geometry.

• Range/Fast-time direction and Azimuth/slow-time direction.
  
  • Azimuth direction data arises out of inter-pulse Doppler generated due to platform motion with respect to ground target.
  • Doppler is also referred to as Phase history.
What is Synthetic Aperture Radar? (Contd.)

- Range and azimuth data are processed to generate SAR image

- Advantages of Synthetic Aperture Radar
  
  - Key advantage being an active sensor system.
  
  - All-Weather Performance, Independent of atmospheric conditions (day, night, fog, rain etc.).
  
  - Foliage Penetration for certain operating Frequencies.
  
  - Long range operation (~200 meters up to few hundred kilometers).
  
  - High resolution imaging (1 meter at orbital altitude of ~500Kms).
SAR Imaging Process

• Ensemble of 2D reflections, each being a reflection from an individual scatterer in the scene
• Small antenna illuminates large swaths on ground
• Phase encoded (either Linear Frequency Modulated-LFM compression or digitally encoded) pulses are transmitted and echoes received
• SAR algorithm processes raw data into an image
  • Synthesizing an aperture as large as the flight path
  • Narrow synthesized beam width, high resolution, high gain
• Best algorithm for each application depends on: geometry and radar parameters, accuracy required, efficiency required
Challenges in Design and Simulation

• The problem is primarily a System development problem

• The problem includes

  • Proof of Concept development
    • Signal Processing Algorithm development
    • Hardware(RF + Baseband Processing)

• Most of the solutions focus on specific targets either RF or Baseband

• The fundamental advantage MATLAB provides is an end-to-end simulation and design of the system.

• Looking at fundamental implementation level, a simple example can be datatypet.
Challenges in Design and Simulation

• The ease MATLAB provides in including equations, generating data pertaining to the equations helps ease the entire chain.

• The typical chain of any prototype development has simulation as its very prominent component.

• Especially, in design of radar systems where the cost of hardware implementation is very high.

• MATLAB provides a platform wherein the entire simulation can be performed in short time.
Modeling in MATLAB

• Entire development can be summarized into 2 parts
  • Simulator Development to generate SAR Raw Data
  • Processing Algorithm Development to process the Raw Data generated from the Simulator

• Simulator development involves:
  • Transmit waveform design and description
  • Platform trajectory description
  • Target description
  • Platform motion and echo return capturing

• Processing Algorithm Development
  • Involves carrier removal
  • Range Processing
  • Motion compensation(optional/depending on requirement)
  • Squint Angle Correction(optional/depending on requirement)
  • Azimuth Processing
System Block Diagram

Input Image (2D Intensity Matrix) → Raw Data Generator (Squint/Broadside) → Output Image (2D Intensity Matrix)

Pre-Processing:
- Range Frequency Transform
- Range Compression
- Range Walk Compensation

Processing:
- Image De-skew for Squinted Data + Inverse transformation
- Modified Omega-K
- Azimuth Frequency Transform
Algorithm Flow

Reference: Mishra N. and Swarup S., “Extended Omega-K Algorithm for High Squint Mode Airborne SAR Imaging with Motion Compensation”, IEEE International Microwave and RF Conference 2014
Modeling in Simulink
Key Modules Involved

Range Matched Filtering

Azimuth Matched Filtering
Conversion Simulink-HDL

2.5 Days for this implementation
Conversion Simulink-HDL (Contd.)
Major Modules Involved

Range Matched Filtering

Azimuth Matched Filtering
SimRF Model for Raw Data Generation

Simple Pulsed Radar Design

LFM Pulsed Radar Design
SAR Simulator GUI Snapshots

Simulator GUI With antenna Side-lobes
SAR Simulator GUI Snapshots

Simulator GUI without antenna Side Lobes at 45° Squint from Direction of Flight Path
Results
Results (Contd.)

Our Processed

![Image 1](image1.png)

![Image 2](image2.png)

Ideal ERS Processed

![Image 3](image3.png)

![Image 4](image4.png)

Courtesy: SAR Remote Sensing Initiative (DLR Germany)
Results (Contd.)

2-D Intensity Matrix  Raw Data for Squint angle of 45°

Final Rotated Image  Range Walk Corrected Image  ω-k Reconstructed SAR Image
Results (Contd.)

Courtesy: SAR Remote Sensing Initiative (DLR Germany)
SAR Imaging on Open-Source Raw Data set, improved resolution with high contrast.
Results (Contd.)

SAR Imaging on Radarsat-1 Raw Data set
• Mishra N. and Swarup S., “Extended Omega-K Algorithm for High Squint Mode Airborne SAR Imaging with Motion Compensation”, IEEE International Microwave and RF Conference 2014


• MATLAB-Simulink Documentation