

Synthetic Aperture Radar Signal Processing

with Matlab Algorithms

MEHRDAD SOUMEKH

Acknowledgements

The work reported in this book was supported by the following government agencies and private industries: National Science Foundation, Grant #MIP-9004996, P. Ramamoorthy, Program Director; Bell Aerospace (Textron), William Zwolinski, Technical Coordinator; Space Computer Corporation, Alan Stocker, Technical Coordinator; Summer Faculty Fellowships at Naval Research and Development (SPAWAR Systems Center), Robert Dinger (1992-95) and Lawrence Hoff (1995), Technical Coordinators; Summer Faculty Fellowship at Rome Laboratory, Air Force Office of Scientific Research, Michael Wicks, Technical Coordinator; Naval Research and Development, Grants #N66001-95-M-1383 and #N66001-7052-7595, Michael Pollock, Technical Coordinator; MITRE Corporation, Richard Perry, Technical Coordinator; Office of Naval Research, Grants #N00014-96-1-0586 and #N00014-97-1-0966, William Miceli, Program Officer; and Air Force Office of Scientific Research, Grant #F49620-99-1-0140, Jon Sjogren, Program Officer. Their generous support of this work is greatly appreciated.

Contents

PREFACE

INTRODUCTION

*Synthetic Aperture Radar
The Book
Organization
SAR and ISAR Databases
List of Figures*

CHAPTER 1 RANGE IMAGING

1.0 Introduction

Outline

Mathematical Notations and Symbols

1.1 System Model

1.2 Reconstruction via Matched Filtering

1.3 Range Resolution

1.4 Data Acquisition and Signal Processing

Time Domain Sampling

Time Interval of Sampling

Number of Time Samples

1.5 Reconstruction Algorithm

1.6 Reconstruction via Pulse Compression for Chirp Signals

Signal Model

Reconstruction

Range Resolution

Time Domain Sampling

Residual Video Phase Error

Upsampling to Recover Alias-Free Echoed Signal

*Electronic Counter-Countermeasure (ECCM) Via Amplitude Modulation
of Chirp Signals*

1.7 Frequency-Dependent Target Reflectivity

Reconstruction via Target Signature Matched Filtering

1.8 Matlab Algorithms

CHAPTER 2 CROSS-RANGE IMAGING

2.0 Introduction

Outline

Mathematical Notations and Symbols

2.1 System Model

2.2 Spherical PM Signal within an Infinite Aperture

2.3 Reconstruction via Matched Filtering: Infinite Aperture

2.4 Spherical PM Signal within a Finite Aperture

Instantaneous Frequency

Slow-Time Fourier Transform

Slow-Time Angular Doppler Spectrum

2.5 Reconstruction via Matched Filtering: Finite Aperture

2.6 Cross-Range Resolution

2.7 Data Acquisition and Signal Processing

Synthetic Aperture Sampling for a Broadside Target Area

Synthetic Aperture Sampling for a Squint Target Area

Reducing PRF via Slow-Time Compression

Cross-Range Gating via Slow-Time Compression

2.8 Reconstruction Algorithm

Baseband Conversion of Target Area

Zero-Padding in Synthetic Aperture Domain

Slow-Time Doppler Domain Subsampling

Reducing Bandwidth of Reconstructed Image

2.9 Synthetic Aperture-Dependent Target Reflectivity

AM-PM Signal Model

Slow-Time Fourier Transform of AM-PM Signal

Example 1: Spotlight SAR

Example 2: Stripmap SAR

Reconstruction

Representation in Slow-Time Angular Doppler Domain

2.10 Reconstruction via Target Signature Slow-time Matched Filtering

Type 1: Generalization of Spotlight SAR

Type 2: Generalization of Stripmap SAR

Type 3: Partial Observability

2.11 Matlab Algorithms

CHAPTER 3 SAR RADIATION PATTERN

3.0 Introduction

Outline

Mathematical Notations and Symbols

3.1 Transmit Mode Radar Radiation Pattern

Example 1: Planar Radar Antenna

Example 2: Parabolic Radar Antenna

Example 3: Circular Radar Antenna

Synthetic Aperture (Slow-Time) Dependence

3.2 Radiation Pattern in Three-Dimensional Spatial Domain

Radar Footprint

Slant-Range

3.3 Transmit-Receive Mode Radar Radiation Pattern

3.4 Transmit-Receive Mode Radar-Target Radiation Pattern

3.5 Polarization

3.6 Matlab Algorithms

CHAPTER 4 GENERIC SYNTHETIC APERTURE RADAR

4.0 Introduction

Outline

Mathematical Notations and Symbols

4.1 System Model

4.2 Fast-Time Fourier Transform

4.3 Slow-Time Fourier Transform

4.4 Reconstruction

4.5 Digital Reconstruction via Spatial Frequency Interpolation

Baseband Conversion of Target Area

Interpolation from Evenly Spaced Data

Interpolation from Unevenly Spaced Data

4.6 Digital Reconstruction Via Range Stacking

Algorithm 1: Fast-Time Slow-Time Matched Filtering

Algorithm 2: Slow-Time Fast-Time Matched Filtering

4.7 Digital Reconstruction Via Time Domain Correlation
and Backprojection

Time Domain Correlation Algorithm

Backprojection Algorithm

4.8 Frequency and Synthetic Aperture-Dependent Target Reflectivity

4.9 Motion Compensation Using Global Positioning System

Spatial Frequency Modeling of Motion Errors

Narrow-Beamwidth Motion Compensation

Wide-Beamwidth Motion Compensation

Three-Dimensional Wide-Beamwidth Motion Compensation

Motion Compensation for Backprojection

4.10 Motion Compensation Using In-Scene Targets

Narrow-Beamwidth Motion Compensation

Wide-Beamwidth Motion Compensation

Three-Dimensional Wide-Beamwidth Motion Compensation

4.11 Polar Format Processing

Plane Wave Approximation-Based Reconstruction

Narrow-Beamwidth Approximation

Narrow-Bandwidth and Narrow-Beamwidth Approximation

Wavefront Curvature Compensation

Motion Compensation Using Global Positioning System

4.12 Conventional ISAR Modeling and Imaging

ISAR Modeling

Slow-Time Compression or Motion Compensation

Polar Format Processing

4.13 Range-Doppler Imaging

Fresnel Approximation-Based Reconstruction

Narrow-Bandwidth and Narrow-Beamwidth Approximation

4.14 Three-Dimensional Imaging With Two-Dimensional Azimuth
and Elevation Synthetic Apertures

System Model

Reconstruction

4.15 Electronic Counter-Countermeasure Via Pulse Diversity

CHAPTER 5 SPOTLIGHT SYNTHETIC APERTURE RADAR

5.0 Introduction

Outline

Mathematical Notations and Symbols

5.1 Mechanically Beam-Steered Spotlight SAR

Mechanical Beam Steering

System Model

Reconstruction

5.2 Electronically Beam-Steered Spotlight SAR

Electronic Beam Steering

System Model

Reconstruction

5.3 Bandwidth of Spotlight SAR Signal

Single Target

Target Area

5.4 Resolution and Point Spread Function

5.5 Data Acquisition and Signal Processing

Fast-Time Domain Sampling and Processing

Slow-Time Domain Sampling and Processing

Reducing PRF via Slow-Time Compression

Digital Spotlighting

Subaperture Digital Spotlighting

5.6 Reconstruction Algorithms and SAR Image Processing

Digital Reconstruction via Spatial Frequency Interpolation

Reconstruction in Squint Spatial Coordinates

Slow-Time Doppler Domain Subsampling

Reducing Bandwidth of Reconstructed Image

Digital Reconstruction via Range Stacking

Digital Reconstruction via Time Domain Correlation and Backprojection

Effect of Slow-time Doppler Filtering

Effect of Motion Errors in Slow-time Doppler Spectrum

5.7 Matlab Algorithms

CHAPTER 6 STRIPMAP SYNTHETIC APERTURE RADAR

6.0 Introduction

Outline

Mathematical Notations and Symbols

6.1 System Model

Radar Radiation Pattern

Stripmap SAR Signal Model

6.2 Reconstruction

6.3 Bandwidth of Stripmap SAR Signal

Planar Radar Antenna

Curved Radar Antenna

6.4 Resolution and Point Spread Function

6.5 Data Acquisition and Signal Processing

Fast-Time Domain Sampling and Processing

Slow-Time Domain Sampling and Processing

Slow-time Compression and Processing

Subaperture Digital Spotlighting

Reducing Side Lobes Doppler Aliasing via Slow-Time Upsampling

6.6 Reconstruction Algorithms and SAR Image Processing

Digital Reconstruction via Spatial Frequency Interpolation

Slow-Time Doppler Domain Subsampling

Reducing Bandwidth of Reconstructed Image

Digital Reconstruction via Range Stacking

Digital Reconstruction via Time Domain Correlation and Backprojection

Effect of Beamwidth (Slow-time Doppler) Filtering

Effect of Motion Errors in Slow-time Doppler Spectrum

Subpatch "Mosaic" Digital Reconstruction with Subaperture Data

6.7 Moving Target Detection and Imaging

SAR Signal Model for a Moving Target with a Constant Velocity

*Three-Dimensional Imaging in Motion-Transformed Spatial Domain
and Relative Speed Domain*

Moving Target Indicator: SAR Ambiguity Function

6.8 Matlab Algorithms

CHAPTER 7 CIRCULAR SYNTHETIC APERTURE RADAR

7.0 Introduction

Outline

Mathematical Notations and Symbols

7.1 System Model

CSAR Signal Model

Fourier Properties of Slant Plane Green's Function

7.2 Reconstruction

Slant Plane to Ground Plane Transformation

Ground Plane CSAR Reconstruction

7.3 Bandwidth of CSAR Signal

7.4 Resolution and Point Spread Function

Full Rotation Aspect Angle Measurement

Partial Rotation Aspect Angle Measurement

7.5 Data Acquisition and Signal Processing

Fast-Time Domain Sampling and Processing

Slow-Time Domain Sampling and Processing

Digital Spotlighting and Clutter Filtering

7.6 Reconstruction Algorithms and CSAR Image Processing

Digital Reconstruction via Spatial Frequency Interpolation

Reducing Bandwidth of Reconstructed Image

Digital Reconstruction via Time Domain Correlation and Backprojection

7.7 Three-Dimensional Imaging

7.8 Target Resolvability from Single Tone Fringe Patterns

7.9 Three-Dimensional Imaging With Two-Dimensional Circular and Elevation Synthetic Apertures

System Model

Reconstruction

Digital Reconstruction

CHAPTER 8 MONOPULSE SYNTHETIC APERTURE RADAR

8.0 Introduction

Outline

Mathematical Notations and Symbols

8.1 Along-Track Moving Target Detector Monopulse SAR

Along-Track Monopulse SAR System Geometry

Monostatic SAR Signal Model

Bistatic SAR Signal Model

Synthesis of Monostatic SAR Signal from Bistatic SAR Signal

Moving Target Indicator

Effect of Variations in Altitude and Nonlinear Motion

8.2 Effect of Uncalibrated and Unstable Radars

Amplitude Patterns of Monopulse Radars

Instability of Monopulse Radars

Wide-Beamwidth Monopulse Radars

8.3 Signal Subspace Registration of Uncalibrated SAR Images

System Model

Signal Subspace Processing

Estimating Calibration Error Impulse Function

Application in MTD Monopulse SAR

Application in Automatic Target Recognition SAR

8.4 Slant Plane Topographic Mapper Monopulse SAR

Slant Plane Monopulse SAR System Geometry

Monostatic and Bistatic SAR Signal Models

Narrow-Bandwidth and Narrow-Beamwidth Approximation:

Interferometric SAR (IF-SAR)

Wide-Bandwidth and Wide-Beamwidth Model

Estimating Slant-Range Shift via Signal Subspace Processing

8.5 Multistatic Monopulse ISAR

Multistatic ISAR Model

Motion Tracking via Signal Subspace Processing

8.6 Matlab Algorithms

BIBLIOGRAPHY

INDEX