Azimuth Ambiguity Suppression for SAR Imaging based on Group Sparse Reconstruction

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-Introduction



(left) SAR Geometry; (right) Radarsat-1 fine mode image.

Synthetic Aperture Radar (SAR)

SAR is a form of imaging radar which obtains high along-track resolution by exploiting the relative motion between antenna and its target region to provide the long-term coherent-signal. It is an active sensing technology, and has the all-time and all-weather observing ability. -Introduction

Compressive Sensing (CS)

CS belongs to the sparse signal processing which theoretically guarantees the quality of reconstruction of a sparse signal from limited samples.

Sparse signal processing based algorithms focus on seek the optimized estimation towards the unknown sparse signal in an effective and fast way with finite number of measurements.

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CS based Radar Imaging

The previous research works try to combine the CS theory with radar imaging framework. Many CS based approaches for radar imaging have been presented.

The Advantages of CS based Radar Imaging

- improve the quality of existing SAR images.
- design ambitious radar imaging systems.

In this paper, we focus on one aspect of improving the SAR imaging quality: suppression of the azimuth ambiguity.

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Azimuth Ambiguity



Example of azimuth ambiguity (orbit number 322 of SEASAT).

The azimuth ambiguity is one of the common problem that degrades the imaging quality and causes difficulties to target recognition in SAR imaging.

-Introduction



Illustration of the cause of azimuth ambiguity.

J. Curlander, et.al. Synthetic aperture radar: systems and signal processing. 1991.

Azimuth Ambiguity

- origin from the extension of antenna pattern.
- cause by limited sampling of doppler spectrum.
- equivalent to solve an <u>underdetermined</u> linear equation.

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-Introduction

In this Paper, we present a new ambiguity supression approach in which:

- **1** the ambiguity is modeled as an underdetermined problem.
- 2 the reflectivity of target is extended as group sparse signal.
- **3** the radar images are recovered by ℓ_q regularization method.

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-Signal Model

Azimuth Signal Model

The SAR azimuth signal model can be expressed as

$$\mathbf{y} = \mathbf{\Phi}\mathbf{x} + \mathbf{n},$$

where the measurement matrix $\boldsymbol{\Phi}$ is a square matrix contains antenna infomation.





- The length of the signal in each row equals to the synthetic aperture length.
- The signal in each column is the azimuth signal.

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–Signal Model

Under-determined Linear Equation

Due to the finite PRF sampling of the doppler spectrum, the azimuth signal can be modeled as under-determined linear equation

$$\mathbf{\Phi} \cdot \mathbf{x} = [\mathbf{\Phi}_{-1}, \mathbf{\Phi}_{0}, \mathbf{\Phi}_{+1}] \cdot \begin{bmatrix} x_{-1} \\ x_{0} \\ x_{+1} \end{bmatrix},$$

where -1, +1 stand for the first left and right ambiguity.



Illustration of azimuth ambiguity model.

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Reconstruction Algorithm

Many sparse recovery algorithm (e.g. l_1 minimizing, OMP, etc.) can solve the above problem. We use ℓ_q regularization algorithm:

$$\arg\min_{\mathbf{x}} \|\mathbf{y} - \mathbf{\Phi}\mathbf{x}\|_2^2 + \lambda \|\mathbf{x}\|_q^q,$$

where $0 < q \leq 1$, λ is the regularization parameter.

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Reconstruction Algorithm



The methodology of <u>group sparse</u> allows the efficient reconstruction of signals whose support is contained in the union of a small number of disjoint groups.

Illustration of group sparse.

Azimuth Ambiguity with Group Sparse

Because the ambiguity component \mathbf{x}_{-1} , \mathbf{x}_{+1} share the same support with the target \mathbf{x}_0 , group sparse can be applied to azimuth ambiguity.



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Reconstruction Algorithm

The group sparsity of ambiguous SAR image **x** defines as a combination of ℓ_2 norm and ℓ_q norm:

$$\rho(\mathbf{x_{-1}}, \mathbf{x_0}, \mathbf{x_{+1}}) = \|(|\mathbf{x}_{-1}|^2 + |\mathbf{x}_0|^2 + |\mathbf{x}_{+1}|^2)\|_q^q,$$

where $|\mathbf{a}|^2 = \text{diag}\{\mathbf{a} * \mathbf{a}^t\}$, **a** is column vector.

Group Sparsity in Azimuth Signal

- The ℓ_2 norm within the signal reassures the same support.
- The ℓ_q norm guarantees the sparse solution.

The group sparse reconstruction algorithm for the azimuth ambiguity suppression:

$$\arg\min_{\mathbf{x}} \|\mathbf{y} - (\sum_{k=-1}^{+1} \boldsymbol{\Phi}_k \mathbf{x}_k)\|_2^2 + \lambda \rho(\mathbf{x}_{-1}, \mathbf{x}_0, \mathbf{x}_{+1}).$$

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Computational Complexity

Why Fast Algorithms are needed

The size of measurement matrix $\mathbf{\Phi}$ is in the square order of the quadratic product of the range and azimuth. It is computational inefficient to directly solve with $\mathbf{\Phi}$.



Assume that the both SAR image and the raw data have 1024 azimuth samples and 1024 range samples, then Φ has <u>1T</u> elements! Azimuth Ambiguity Suppression based on Group Sparse Reconstruction

Computational Complexity

Range-Azimuth Decoupling

The range-azimuth decoupling lies in the formation of SAR signal from the reflectivity image of the observation area. In this way, the matrix $\boldsymbol{\Phi}$ can be factorized into several small matrixes and the reconstruction can be efficiently carried out.



Illustration of range-azimuth decoupling.

For example, the computation complexity reduces from <u>300 hour</u> to <u>30 min</u> compared with non-decoupling algorithm when SAR data is 8192*8192. Zhang B C, et.al. Sparse microwave imaging: Principles and applications. Sci China, 2012, 55. Jian F, et.al. Fast Compressed Sensing SAR Imaging based on Approximated Observation.

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Experimental Results

Point Target Simulations, 1D



(left) RDA; (mid) ℓ_q method without group sparse; (right) ℓ_q method with group sparse.

The peak Azimuth Ambiguity to Signal Ratio (AASR) is reduced 23dB by the proposed method compared with traditional range doppler algorithm, which demonstrates the effectiveness of the proposed method.

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-Experimental Results

Point Target Simulations, 2D



2D impulse response of single point target.

(left) RDA; (mid) ℓ_q method without group sparse; (right) ℓ_q method with group sparse.

The Azimuth Ambiguity is suppressed quite well by the proposed method, which demonstrates the effectiveness of the proposed method.

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-Experimental Results

SAR Data



Result of the SAR data.

(left) RDA; (right) The proposed method.

The ambiguity in the scene is numerically simulated. The result by the proposed method shows that the ambiguity (within the red rectangle) is suppressed quite well compared with the result by Range Doppler algorithm.

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Conclusion

In this paper, we present a group sparse modeling based method for azimuth ambiguity suppression:

- The proposed method investigates the feature of the azimuth ambiguity problem and models it with under-determined linear equation and group sparse signal. Experimental results verified its effectiveness.
- The proposed method has the potential to be applied to the <u>real SAR data</u> because of its computational efficiency.
- The proposed method can be extended to solve range ambiguity problem.

Fang J, Xu Z B, Jiang C L, Zhang B C, Hong W: SAR range ambiguity suppression via sparse regularization. IGARSS 2012: 3811-3814.

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Thanks!

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