Poster for: Algorithms for Synthetic Aperture Radar Imagery XIV (Proc. SPIE vol. 6568), Orlando FL, April 2007.

THE OHIO STATE UNIVERSITY

Joint Enhancement of Multichannel SAR Data

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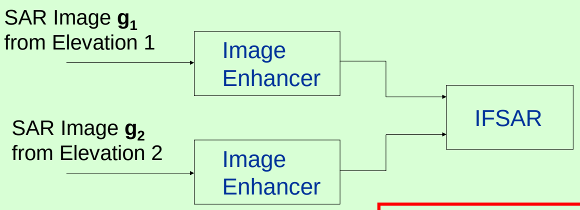
Research Goal:

Joint, deconvolution-based sparse SAR image reconstruction techniques to preserve phase information for 3D reconstruction, such as IFSAR

Independent Enhancement



Each Image Enhancer (Cetin SPIE 2005) solves:

$$\arg\min_{\boldsymbol{f_i}} \quad \|\boldsymbol{g_i} - \boldsymbol{T f_i}\|_2^2 + \lambda^2 \|\boldsymbol{f_i}\|_p^p \qquad i = 1, \dots, N$$

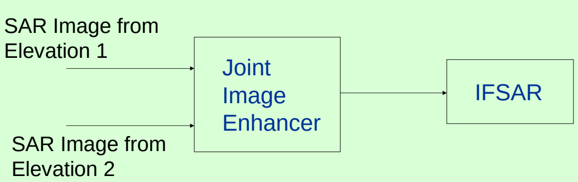
Two constrained optimizations each with 2N real variables

Problems

Relative phase of enhanced images may not be preserved

Sparse basis selection may be different for each image

Joint Enhancement



The Joint Image Enhancer in this case solves the following optimization problem,

$$\arg\min_{\boldsymbol{f_1},\boldsymbol{f_2}} \quad \|\boldsymbol{g_1} - \boldsymbol{T_1 f_1}\|_2^2 + \|\boldsymbol{g_2} - \boldsymbol{T_2 f_2}\|_2^2 + \lambda_1^2 \|\boldsymbol{f_1}\|_p^p + \lambda_2^2 \|\boldsymbol{f_2}\|_p^p$$

with a constraint that, $|(\vec{f}_1)_i| = |(\vec{f}_2)_i| \qquad i = (1, \dots, N)$

One constrained optimization with 4N real variables

Solution 1: Gradient Descent Method

Idea: Directly include constraint in the cost function

$$\boldsymbol{f_1} = e^{j\boldsymbol{\phi_1}} |\boldsymbol{f}| \qquad \boldsymbol{f_2} = e^{j\boldsymbol{\phi_2}} |\boldsymbol{f}|$$

The Gradient Descent update equation is given by,

$$|\boldsymbol{f}^{k+1}| = |\boldsymbol{f}^k| + \gamma_1 \nabla \boldsymbol{L}_{|\boldsymbol{f^k}|}$$
$$\boldsymbol{\phi_1}^{k+1} = \boldsymbol{\phi_1}^k + \gamma_2 \nabla \boldsymbol{L}_{\boldsymbol{\phi_1}^k}$$
$$\boldsymbol{\phi_2}^{k+1} = \boldsymbol{\phi_2}^k + \gamma_2 \nabla \boldsymbol{L}_{\boldsymbol{\phi_2}^k}$$

Advantage: Ensures $|(\vec{f}_1)_i| = |(\vec{f}_2)_i|$

Solution 2: Lagrange-Newton Method

In this method, the constraint is included in the cost function using a Lagrangian term

$$\min_{\boldsymbol{f_1},\boldsymbol{f_2}} \max_{\boldsymbol{\beta}} \quad \|\boldsymbol{g_1} - \boldsymbol{T_1 f_1}\|_2^2 + \|\boldsymbol{g_2} - \boldsymbol{T_2 f_2}\|_2^2 + \lambda_1^2 \|\boldsymbol{f_1}\|_p^p + \lambda_2^2 \|\boldsymbol{f_2}\|_p^p + \sum_{i=1}^{N} \beta_i (|(\boldsymbol{f_1})_i|^2 - |(\boldsymbol{f_2})_i|^2)$$

Lagrange multipliers β_is are also iteratively updated

$$\nabla_{\boldsymbol{xx}} \boldsymbol{L} \, \Delta \boldsymbol{x} \;=\; \boldsymbol{a}$$

$$\Delta \boldsymbol{x} \;=\; \begin{bmatrix} \Delta \boldsymbol{f_1} \\ \Delta \boldsymbol{f_2} \\ \Delta \boldsymbol{\beta} \end{bmatrix}$$

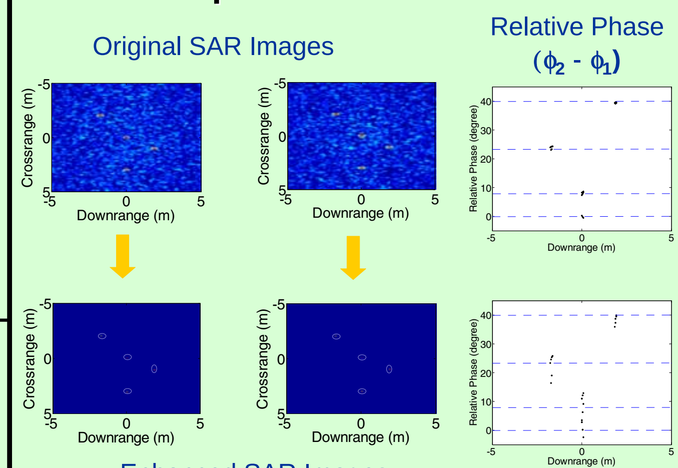
$$\nabla_{\boldsymbol{xx}} \boldsymbol{L} \;=\; \begin{bmatrix} \boldsymbol{R_1^H R_1} + \begin{bmatrix} \frac{\boldsymbol{\Lambda_1}}{\boldsymbol{\Lambda_1}} \end{bmatrix} + 2 \begin{bmatrix} \frac{\boldsymbol{B}}{\boldsymbol{B}} \end{bmatrix} & 0 & 2 \begin{bmatrix} \frac{D[\boldsymbol{f_1}^r]}{D[\boldsymbol{f_1}^i]} \end{bmatrix} \\ 0 & \boldsymbol{R_2^H R_2} + \begin{bmatrix} \frac{\boldsymbol{\Lambda_2}}{\boldsymbol{\Lambda_2}} \end{bmatrix} - 2 \begin{bmatrix} \frac{\boldsymbol{B}}{\boldsymbol{B}} \end{bmatrix} & -2 \begin{bmatrix} \frac{D[\boldsymbol{f_2}^r]}{D[\boldsymbol{f_2}^i]} \end{bmatrix} \\ 2[\; D[\boldsymbol{f_1}^r] \mid D[\boldsymbol{f_1}^i] \;] & -2[\; D[\boldsymbol{f_2}^r] \mid D[\boldsymbol{f_2}^i] \;] & 0 \end{bmatrix}$$

5N x 5N structured matrix equation solving at each iteration

Example

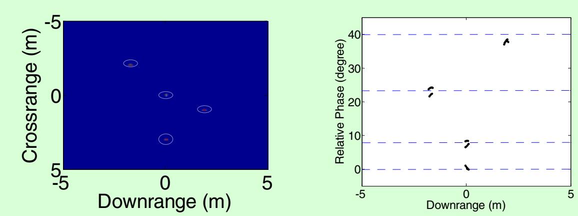
- 4 Point Scatterers
- IFSAR aperture pair: 29.5°, 29.57° elevations
  - X-band: fc = 10GHz, BW = 1GHz, 20° azimuth
  - Peak SNR = 21 dB

Independent Enhancement



Independent enhancement does not preserve the interchannel information needed for accurate IFSAR height estimation

Joint Enhancement (Gradient Descent Method)



Joint Enhancement leads to:

- Lower inter-channel phase error (better IFSAR height estimation)
- Preservation of more dominant pixels