Autofocus for CS Based ISAR Imaging in the presence of Gapped Data

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Overview

- CS applicability to ISAR imaging
- Signal model
- CS for gapped data in the slow time domain
- Autofocusing algorithms
  - Conventional ICBA
  - Optimal approach for gapped data
  - Multi-window ICBA
- Simulation results
- Conclusions
ISAR image can be considered as **intrinsically sparse** since the number of dominant scatterers is much smaller than the number of pixels in the image.

Suitable for Compressive Sensing application

**Applications:**

- ISAR image reconstruction with data sampling rate lower than the Nyquist bound
- Resolution enhancement both in the delay-time and Doppler domain
- ISAR imaging with incomplete data in the slow-time/ Doppler domain

Common assumption: **motion compensated** data
Output of the matched filter:

\[ S(m,n) = CW(m,n) \sum_{k=1}^{K} \sigma_k e^{-j2\pi \frac{m q_k}{Q}} e^{-j2\pi \frac{n d_k}{D}} e^{-j\frac{4\pi m \Delta f}{c}} R_0(n) \]

- \( m = 0,1,\ldots, N_f - 1 \)
- \( n = 0,1,\ldots, N_s t - 1 \)
- \( d = 0,1,\ldots, D - 1 \)
- \( q = 0,1,\ldots, Q - 1 \)

\( W(m,n) \) Discrete frequency-slow time domain in which the signal is defined

Well performed motion compensation \( \rightarrow \) \( S_c(m,n) = CW(m,n) \sum_{k=1}^{K} \sigma_k e^{-j2\pi \frac{m q_k}{Q}} e^{-j2\pi \frac{n d_k}{D}} \)

\[ S_c = \Psi_D I \Psi_R^T \]

- \( S_c \) Non sparse data (complete received signal \textbf{after motion compensation})
- \( I \) ISAR image, which is assumed intrinsically sparse
- \( \Psi_D \) Fourier matrix
- \( \Psi_R \) Fourier matrix

Matrix bases that define the space, i.e. the \textbf{image domain}, in which the available data is sparse
Multitracking radar systems that collect data of different targets in non adjacent time intervals

- The effectiveness of conventional reconstruction algorithms is reduced because of the lack of information in the data
- CS is an effective alternative for gapped data reconstruction

\[ \min_{I} \| I \|_0 \quad \text{s.t.} \quad S_{cg} = \Theta_D \Psi_R^T \]
Iterative algorithm based on the maximization of the image contrast for the estimation of $\hat{R}_0(t)$ where $\hat{R}_0(t) = \sum_{p=0}^{P} \Gamma(p) t^p$

For each iteration,

- The use of 2D-FFT in case of gapped data leads to distorted ISAR images

**CS-ICBA**

The optimum solution consists of the

- Computationally expensive leading to high processing time.

**ICBA**

- Conventional FFT based ICBA applied to the whole gapped data
- The image reconstruction is performed via CS

```
\hat{\Gamma}_{\text{opt}}
```

- Faster than the CS-ICBA
**Multi-window ICBA**

- Conventional FFT reconstruction applied to each window of the gapped data (*)
- The estimation of $\hat{R}_{0opt}(t)$ is performed considering the product of the image contrast values of each slow time window
- Considering the $i^{th}$ iteration:

\[
\hat{\Gamma}_i = \arg\max_{\Gamma} \{ IC_{prod}(\Gamma) \}
\]

(*) Each window of the gapped data is complete in the slow time domain so the conventional 2D-FFT reconstruction does not cause distortions
CS-ISAR: Simulation Results

Complete Data

2D-FFT on complete data

Gapped Data

2D-FFT

CS

Central Frequency: 10GHz
Bandwidth: 300MHz
Observation Time: 0.8 sec
Pulse Repetition Frequency: 158.75Hz
CS-ISAR: Simulation Results

2D-FFT on complete data

CS - motion compensated data

CS without autofocusing
ICBA: Simulation Results

**ICBA+CS**

\[ IC_{ICBA+CS} = 5,6553 \]

**Multiwindow ICBA**

\[ IC_{MW-ICBA} = 5,4662 \]
ICBA: Simulation Results

<table>
<thead>
<tr>
<th></th>
<th>Real</th>
<th>ICBA+CS</th>
<th>Multiwindow ICBA</th>
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<tbody>
<tr>
<td>$\gamma_1$</td>
<td>8</td>
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<td>$\gamma_2$</td>
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$IC(\Gamma)$

$IC_{prod}(\Gamma)$
Conclusions

- CS as a powerful tool for ISAR applications:
  - imaging from gapped data,
  - Image reconstruction in data with data sampling rate lower than the Nyquist bound,
  - enhanced resolution in ISAR imaging

- Autofocusing as crucial step to apply CS

- 2D-FFT introduces distortion in the image reconstruction from gapped data so conventional ICBA could be not effective due to the presence of local maxima in the cost function

- Optimal approach: ICBA based on CS image reconstruction at each iteration → too high computational time

- Multi-window ICBA based on the product of image contrast evaluated on each window
  - No distortion introduced by the 2D-FFT on the image reconstruction from each window, which is a complete data
  - No local maxima in the cost function
THANK YOU

Q & A