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

CS-ISAR: Signal Model

Output of the matched filter:

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

$$m = 0,1,\ldots,N_f - 1$$
$$n = 0,1,\ldots,N_{st} - 1$$
$$d = 0,1,\ldots,D-1$$
$$q = 0,1,\ldots,Q-1$$

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

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

$$\mathbf{S}_c = \mathbf{\Psi}_D \mathbf{I} \mathbf{\Psi}_R^T$$

$\mathbf{S}_c$ Non sparse data (complete received signal **after motion compensation**)

$\mathbf{I}$ ISAR image, which is assumed intrinsically sparse

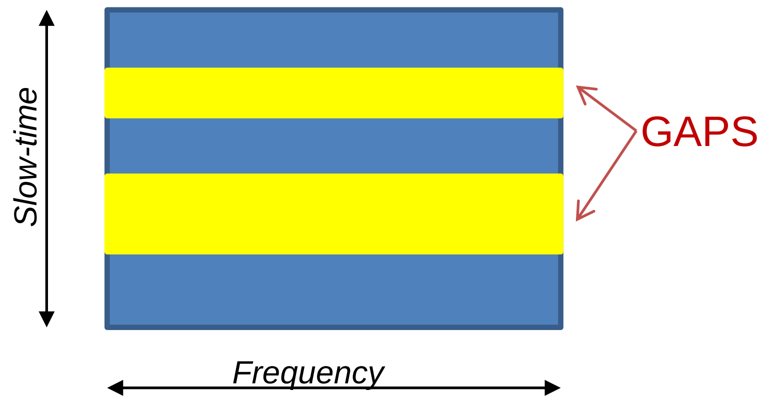
$\mathbf{\Psi}_D$ Fourier matrix

$\mathbf{\Psi}_R$ Fourier matrix

Matrix bases that define the space, i.e. the ***image domain***, in which the available data is sparse

CS-ISAR: Gapped data in the slow-time domain

Multitracking radar systems that collect data of different targets in non adjacent time intervals



$\mathbf{\Psi}_D$ is zero where the signal gaps are $\rightarrow \mathbf{\Theta}_D$

$$\mathbf{S}_{cg} = \mathbf{\Theta}_D \mathbf{I} \mathbf{\Psi}_R^T$$

- 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

$$\min_{\mathbf{I}} \|\mathbf{I}\|_0 \quad \text{s.t.} \quad \mathbf{S}_{cg} = \mathbf{\Theta}_D \mathbf{I} \mathbf{\Psi}_R^{\mathrm{T}}$$

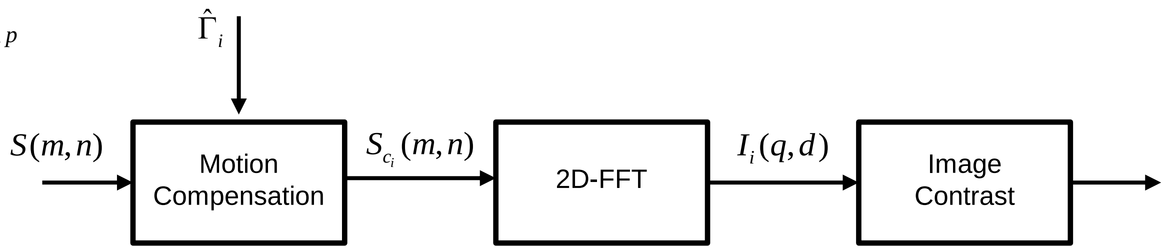
CS-ISAR: Motion compensation

Image Contrast Based Autofocusing (ICBA) [1]

Iterative algorithm based on the maximization of the image contrast for the estimation of $\hat{R}_0(t)$

where $\hat{R}_0(t) = \sum_{p=0}^{P} \Gamma(p) t^p$

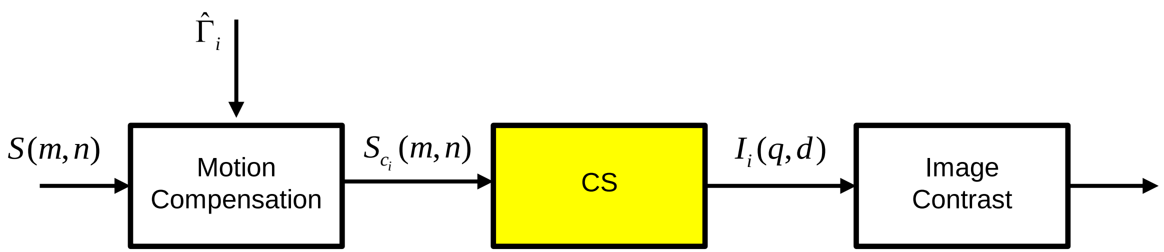
For each iteration,



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

CS-ICBA

The optimum solution consists of the



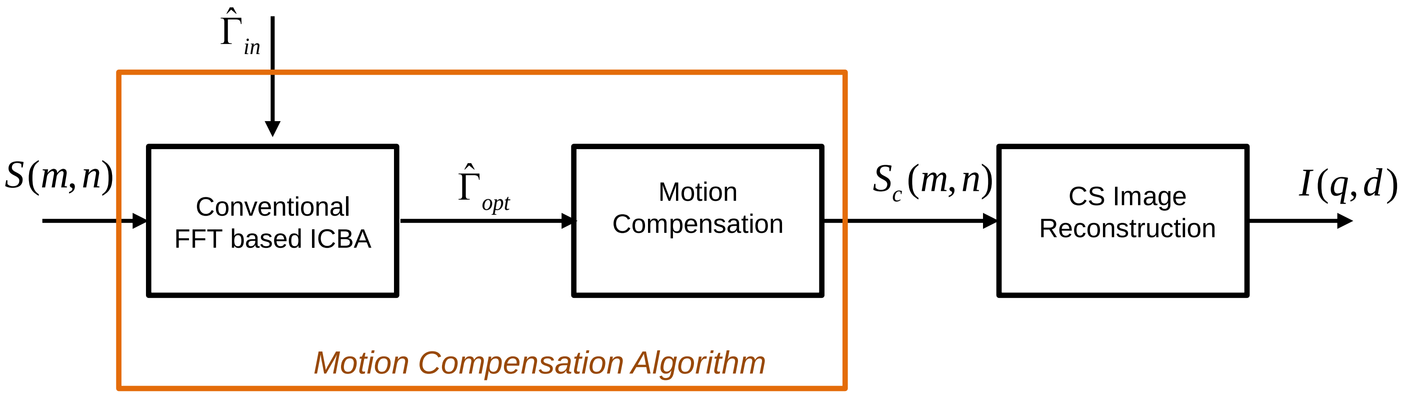
- Computationally expensive leading to high processing time.

[1] M. Martorella, F. Berizzi, B. Haywood, "*Contrast maximization based technique for 2-D ISAR autofocusing*", Radar, Sonar and Navigation, IEE Proceedings, vol. 152, no.4, pp. 253-262, 2005

CS-ISAR: Motion compensation for gapped data

ICBA

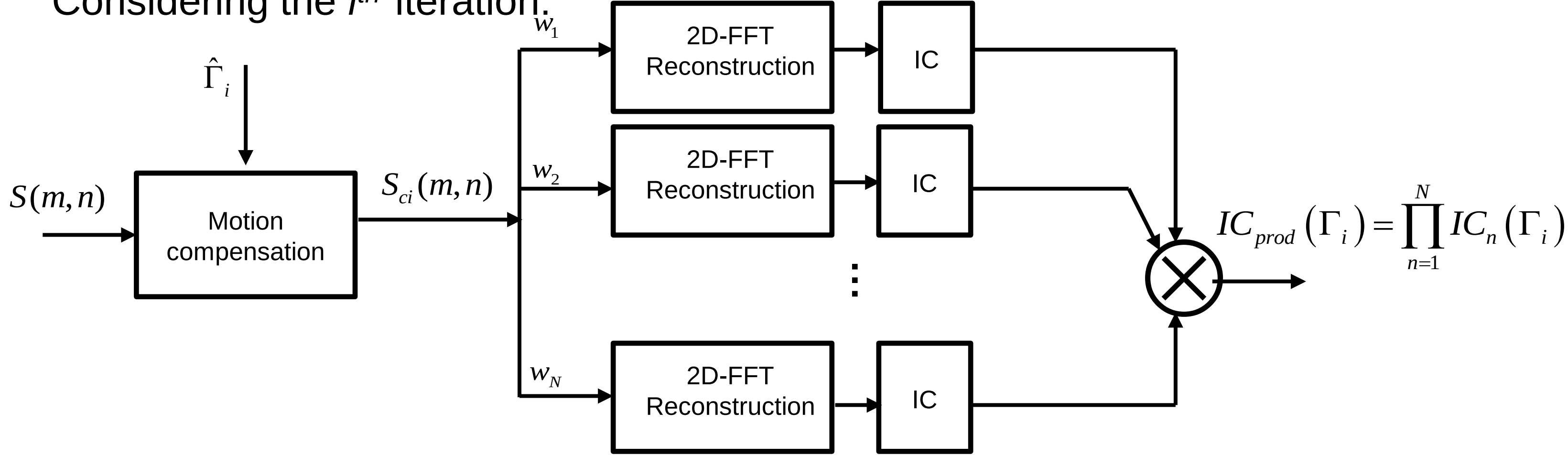
- Conventional FFT based ICBA applied to the whole gapped data
- The image reconstruction is performed via CS



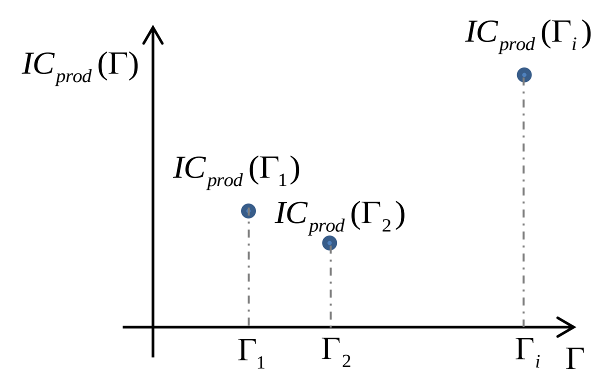
- Faster than the CS-ICBA

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:

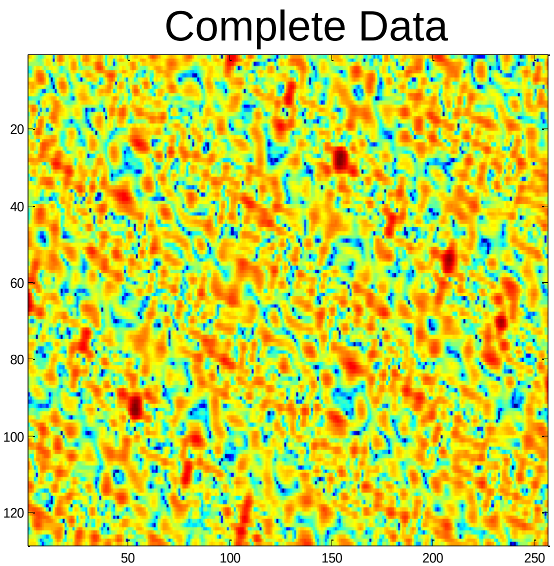


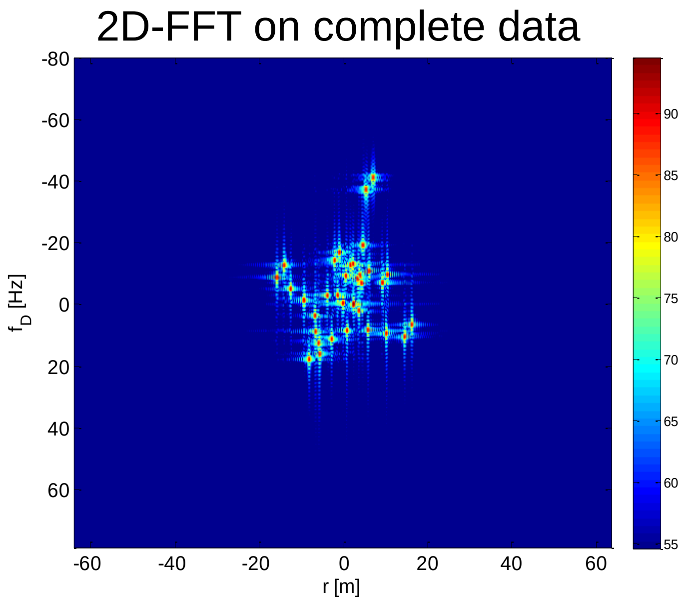
$$\boxed{\hat{\Gamma}_{opt} = \underset{\Gamma}{argmax}\{IC_{prod}(\Gamma)\}}$$

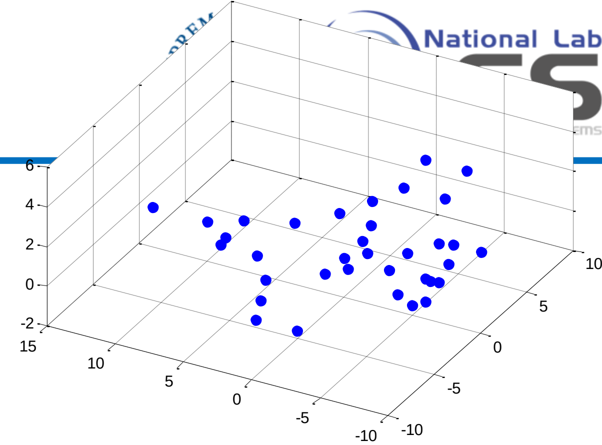


(*) *Each window of the gapped data is complete in the slow time domain so the conventional 2D-FFT reconstruction does not cause distortions*

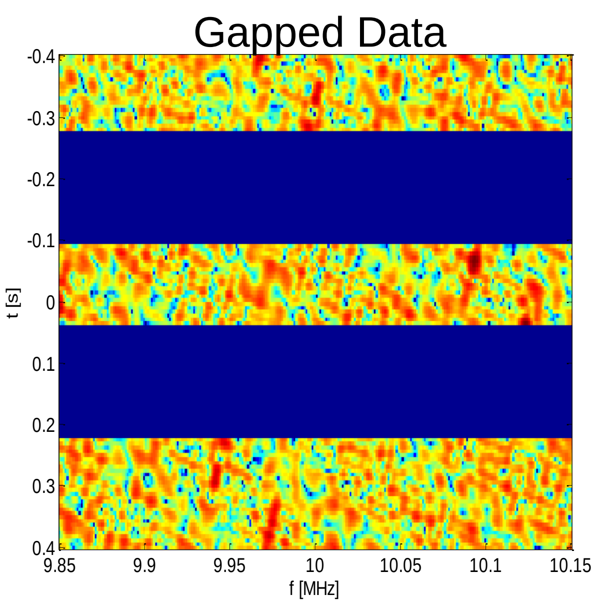
CS-ISAR: Simulation Results

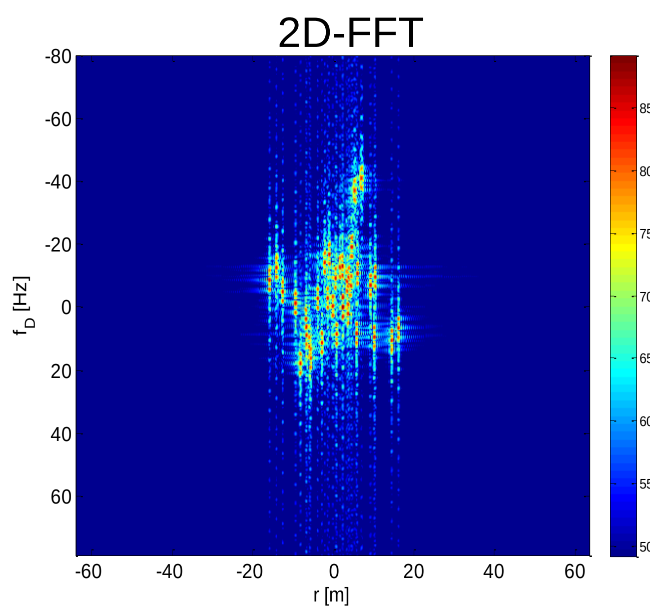


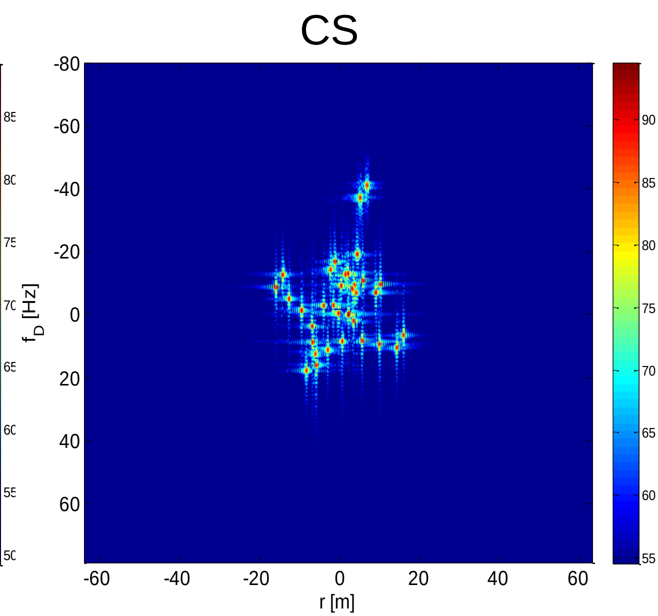




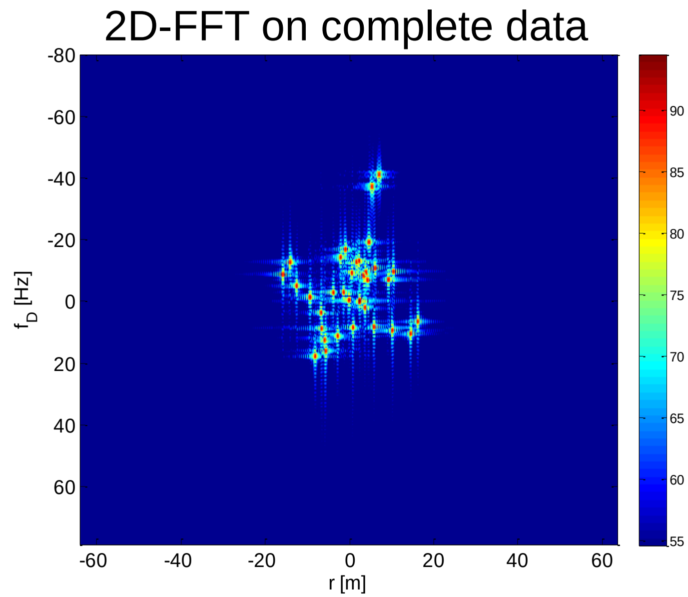
Central Frequency	$10GHz$
Bandwidth	$300MHz$
Observation Time	$0.8\,\text{sec}$
Pulse Repetition Frequency	$158.75Hz$

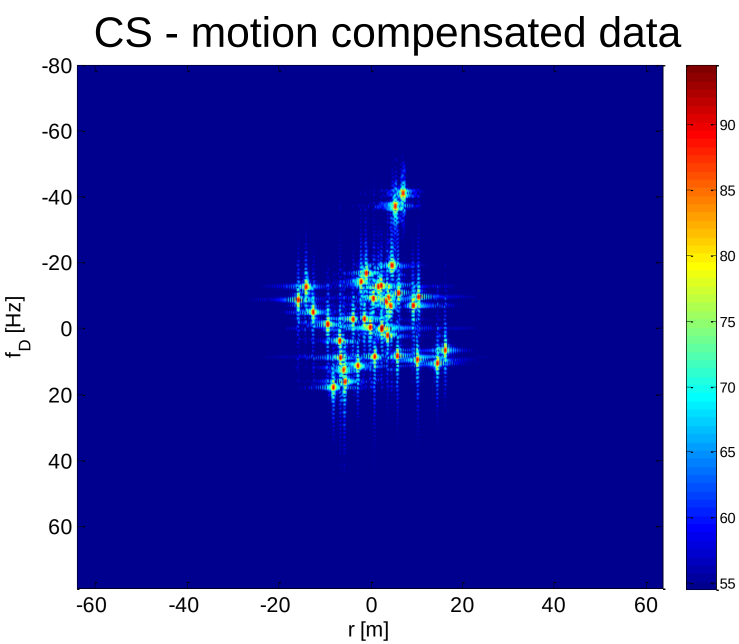


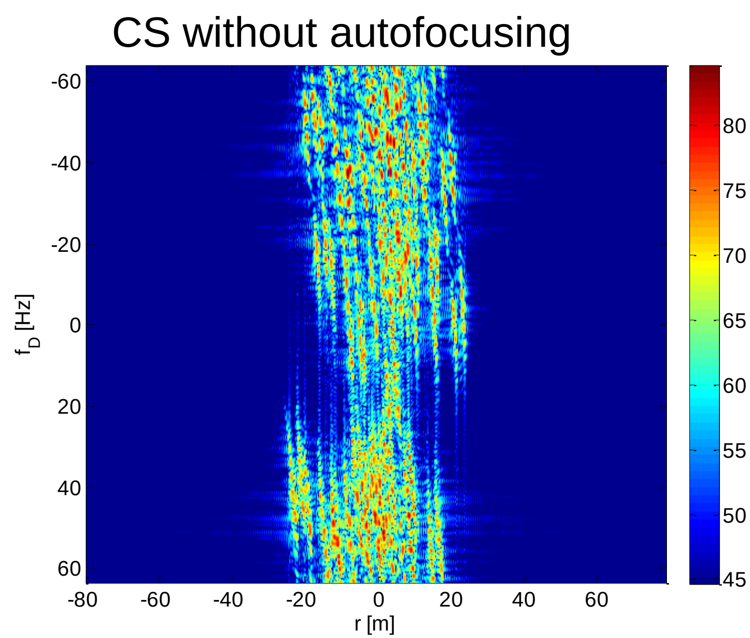




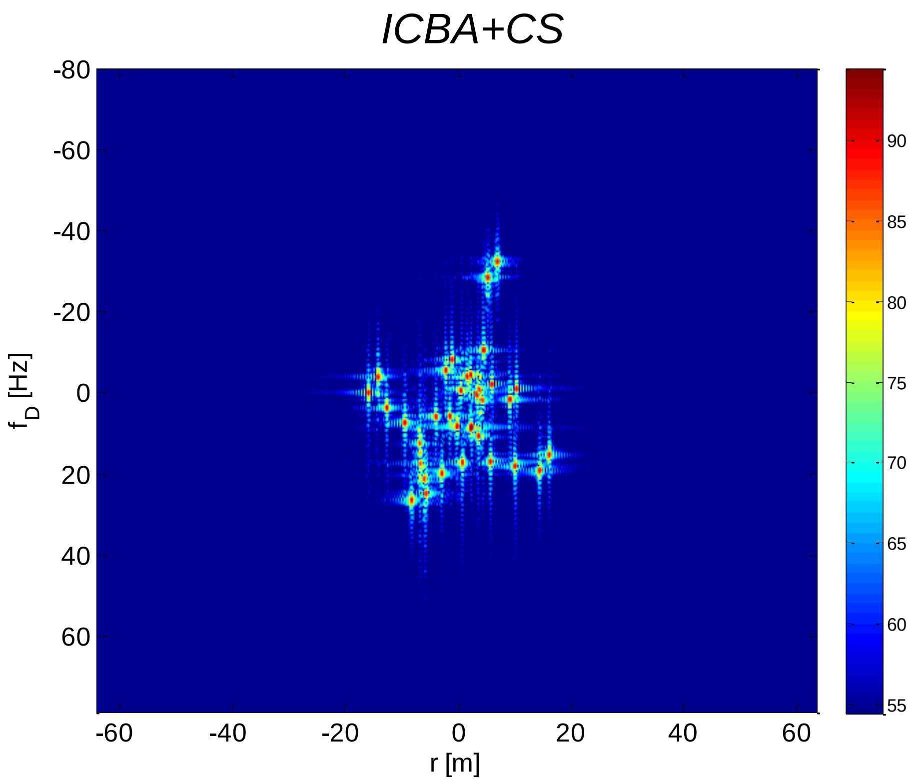
CS-ISAR: Simulation Results



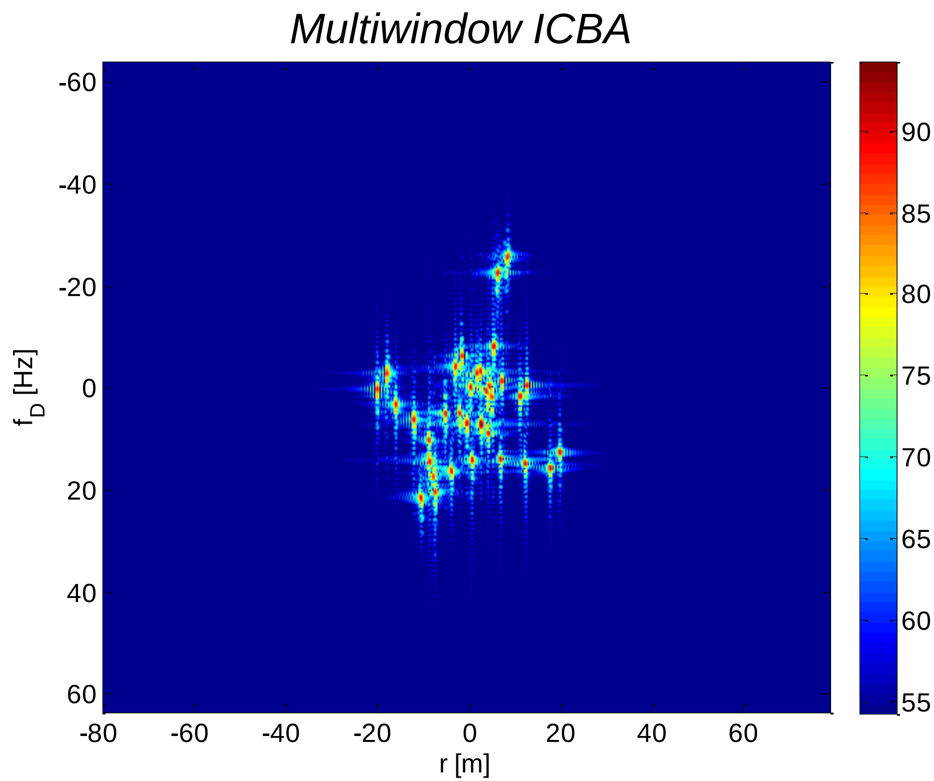




ICBA: Simulation Results



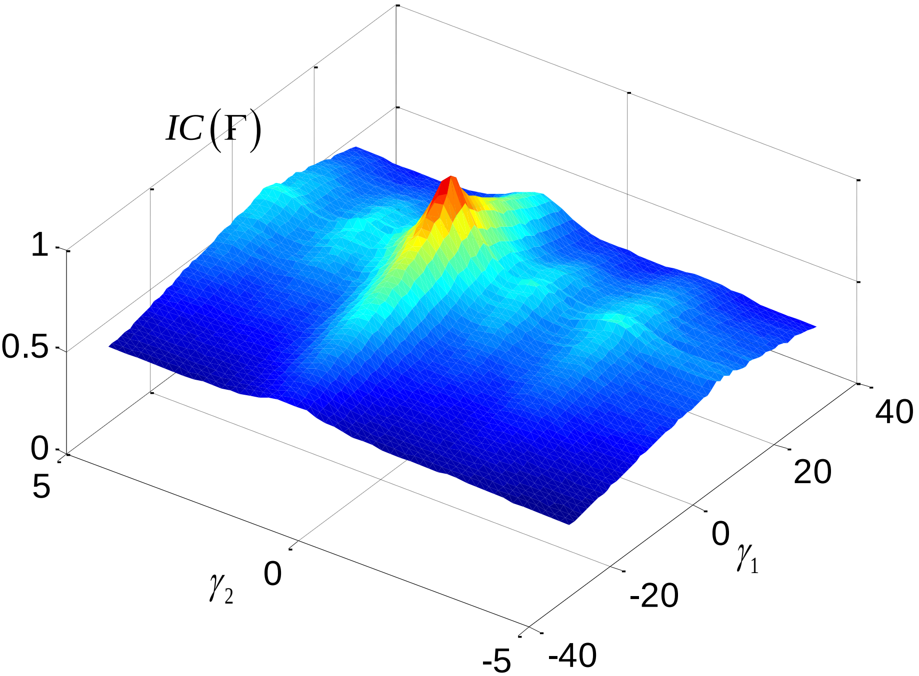
$$IC_{ICBA+CS} = 5,6553$$

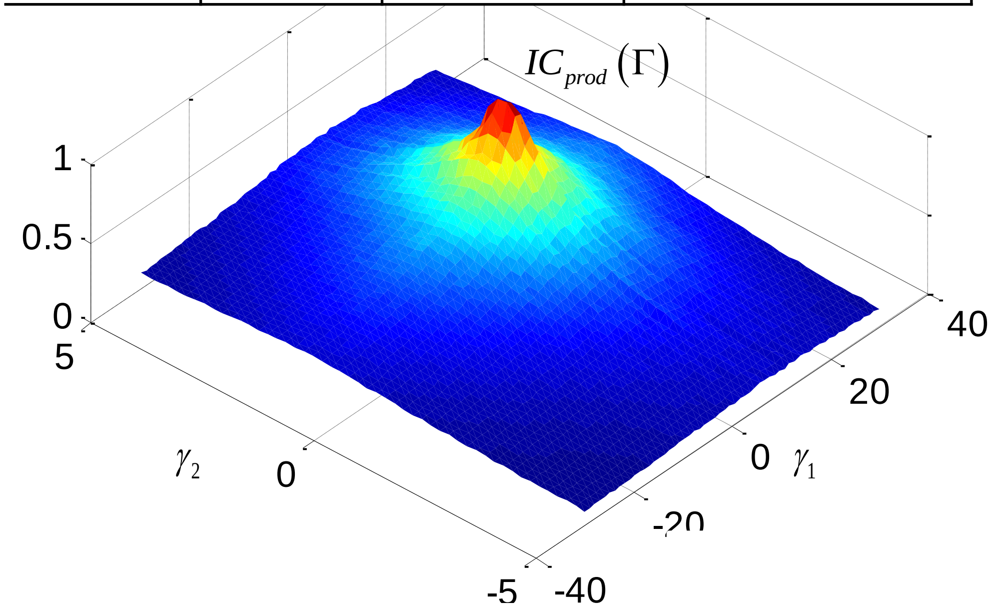


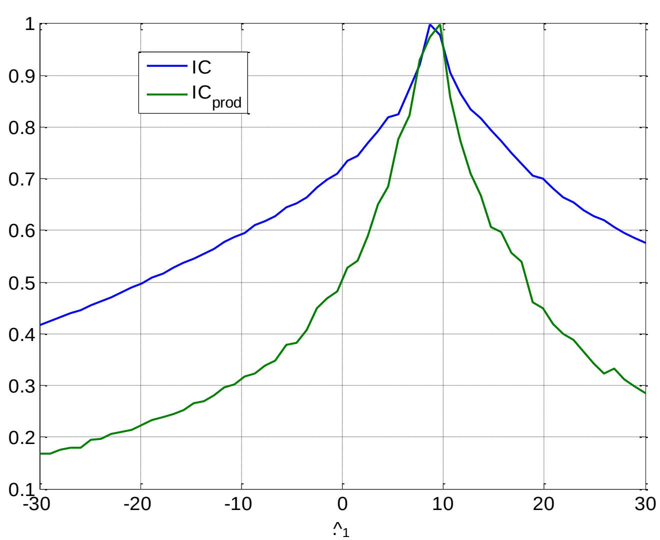
$$IC_{MW-ICBA} = 5,4662$$

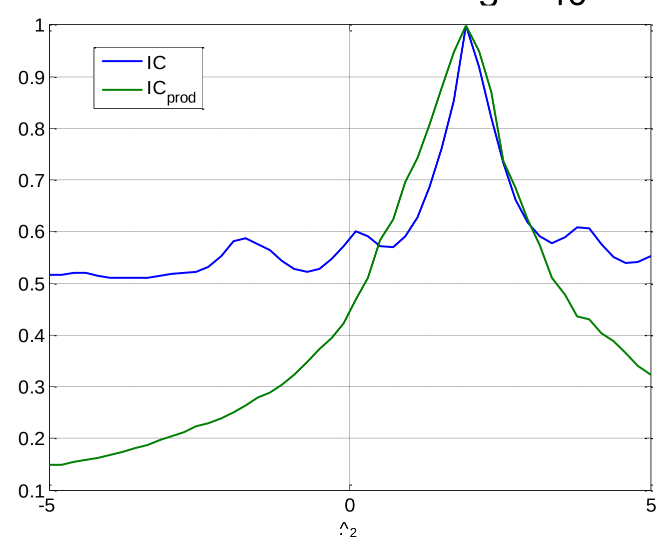
ICBA: Simulation Results

	Real	ICBA+CS	Multiwindow ICBA
γ_1	8	8.1298	8.1265
γ_2	1	1.0006	1.0161









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