Compressed Sensing Based Methods for Switched Array Imaging

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Qiao Cheng, Akram Alomainy, Yang Hao

Antennas & Electromagnetics Group

CIS centre for intelligent sensing

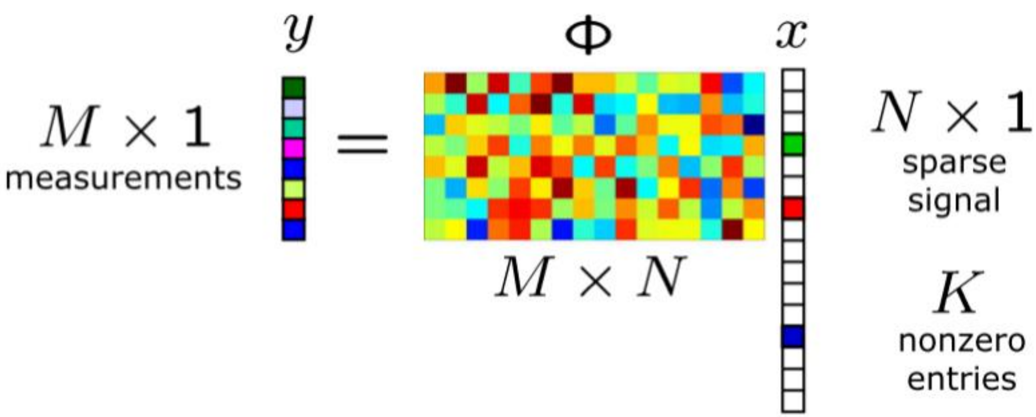
Queen Mary University of London

Outline

1. Compressive sensing (CS) background
2. CS based array imaging
3. Performance analysis
4. Conclusion

Compressive sensing

Linear system



Sensing and compressing

$$y = \Phi x$$

Reconstruction

$$\min_{x} \|x\|_0 \quad s.t. \quad y = \Phi x$$

Necessary condition for CS reconstruction:

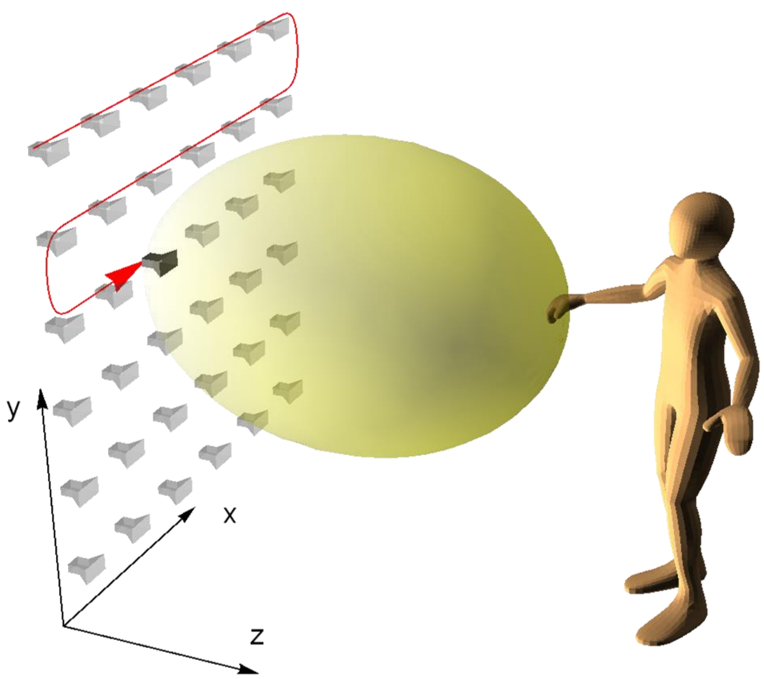
1. Φ satisfy the RIP or Φ has low mutual coherence.
2. Signal x is sparse or x is compressible in a certain basis.

Outline

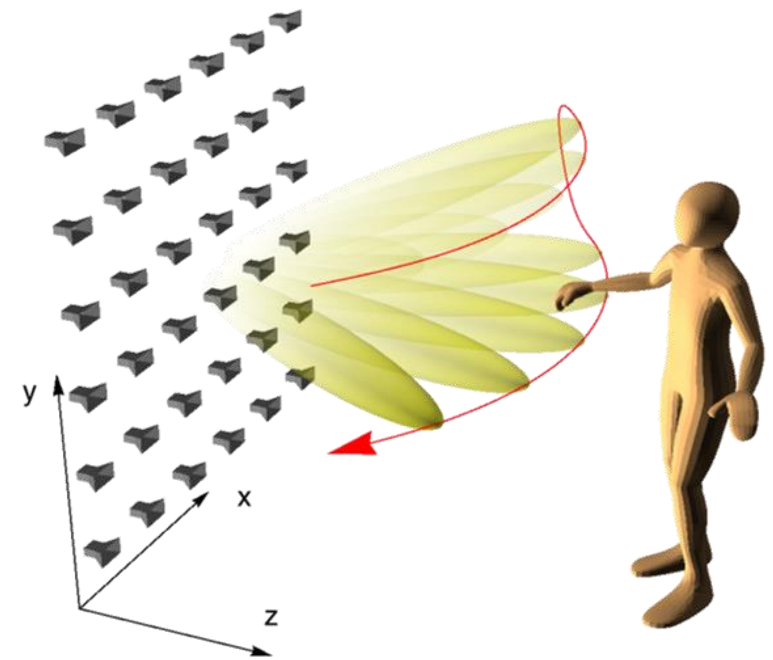
CS based array imaging

Array model

SAR Scheme

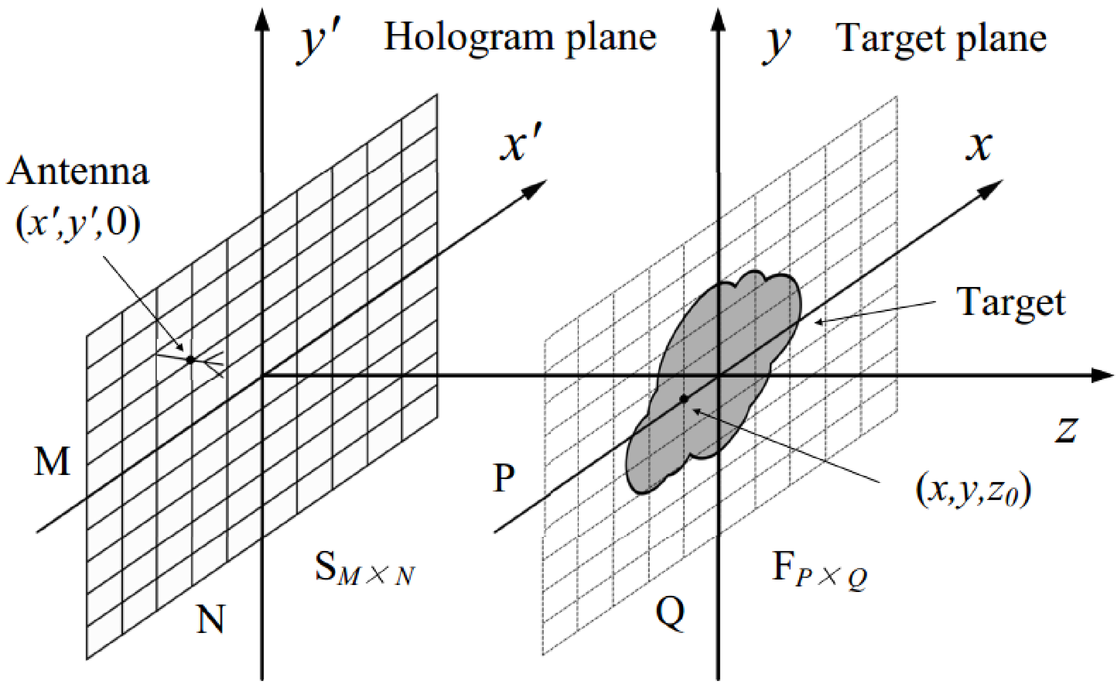


Phased Array Scheme



CS based array imaging

Switched array

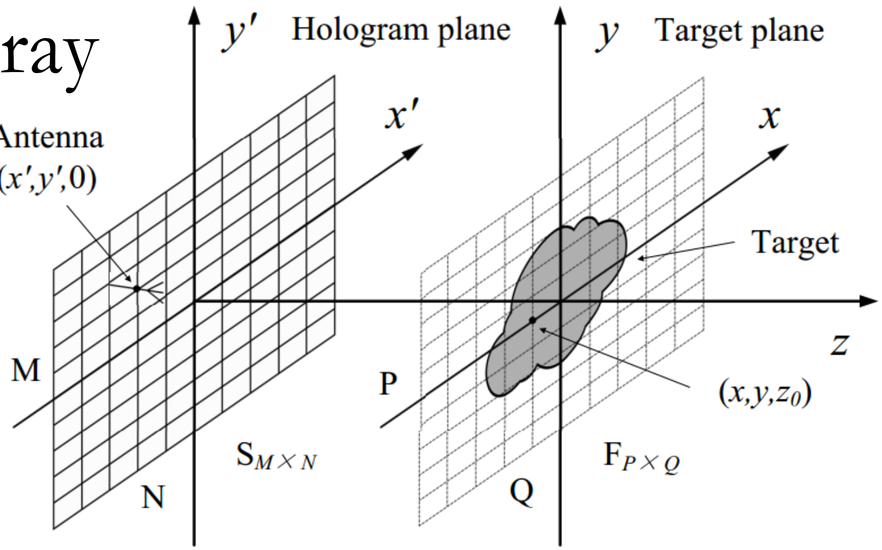


Forward model

$$s(x',y') = \iint f(x,y)\exp(-j2kR)\,dx\,dy.$$

CS based array imaging

Switched array



FT-CS

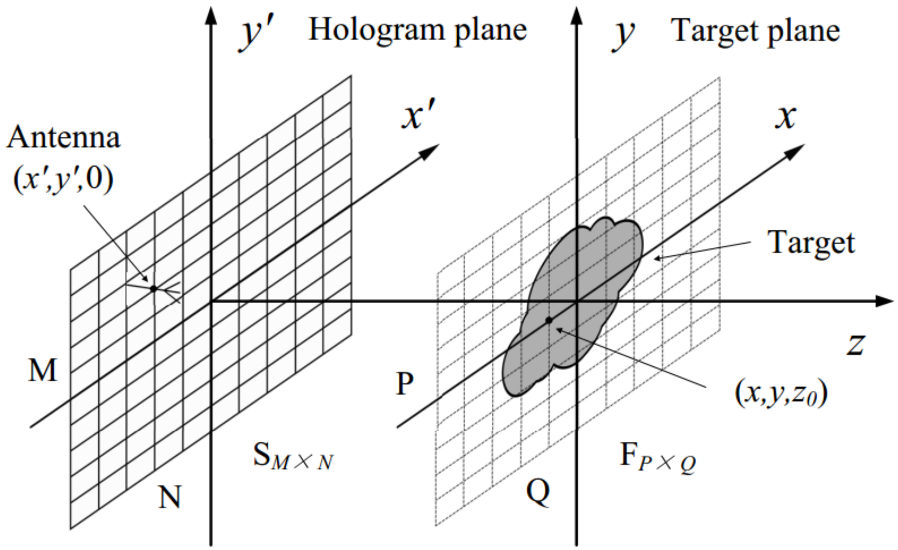
Forward model

$$\boldsymbol{S} = \boldsymbol{H}\boldsymbol{F}, \quad \boldsymbol{H} = FT_{2D}^{-1}[FT_{2D}[\cdot]\exp(jk_z z_0)]$$

Backward model (backpropagation algorithm)

$$\boldsymbol{F} = \boldsymbol{H}^{\dagger}\boldsymbol{S}, \quad \boldsymbol{H}^{\dagger} = FT_{2D}^{-1}[FT_{2D}[\cdot]\exp(-jk_z z_0)]$$

CS based array imaging



Forward model

$$s(x',y') = \iint f(x,y)\exp(-j2kR)\,dx\,dy.$$

D-CS

$$\boldsymbol{s} = \boldsymbol{A}\boldsymbol{f} \qquad s(m,n) = \sum_{i=1}^{P}\sum_{j=1}^{Q} f(i,j)\exp(-j2kR(m,n,i,j))$$

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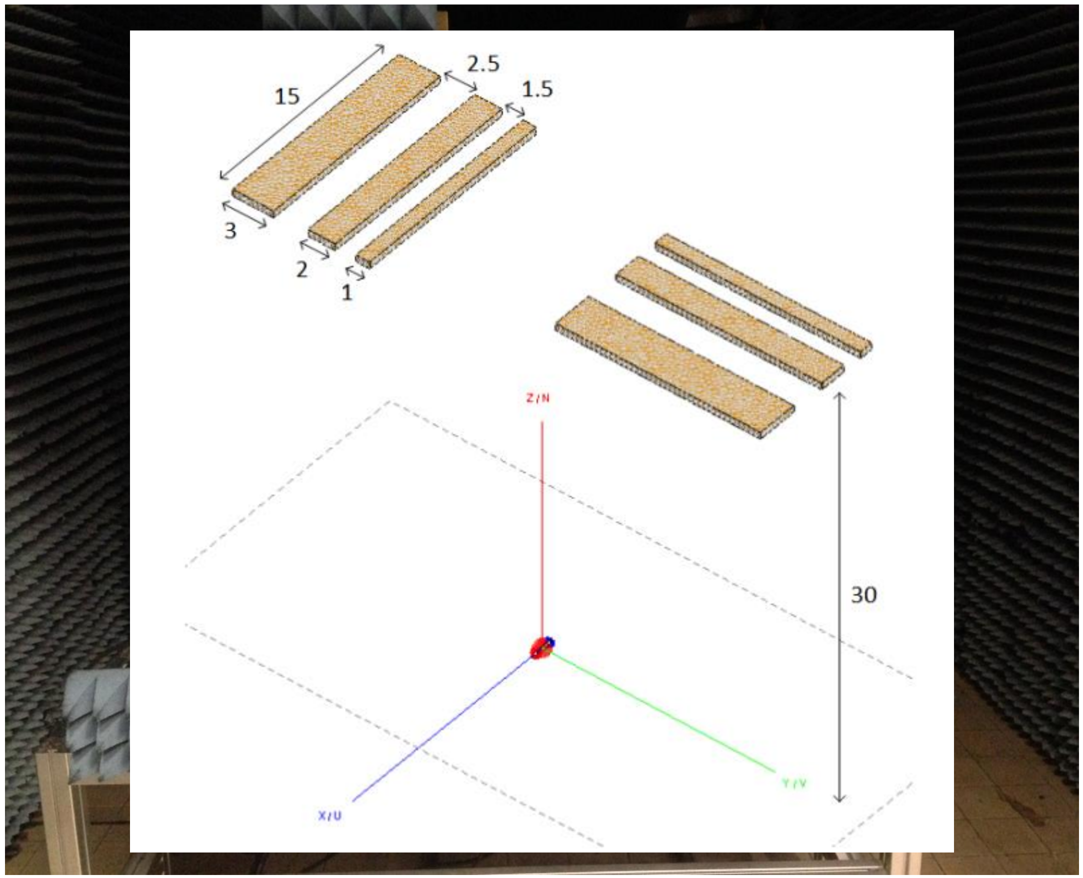
Performance Analysis

Simulation and experiment

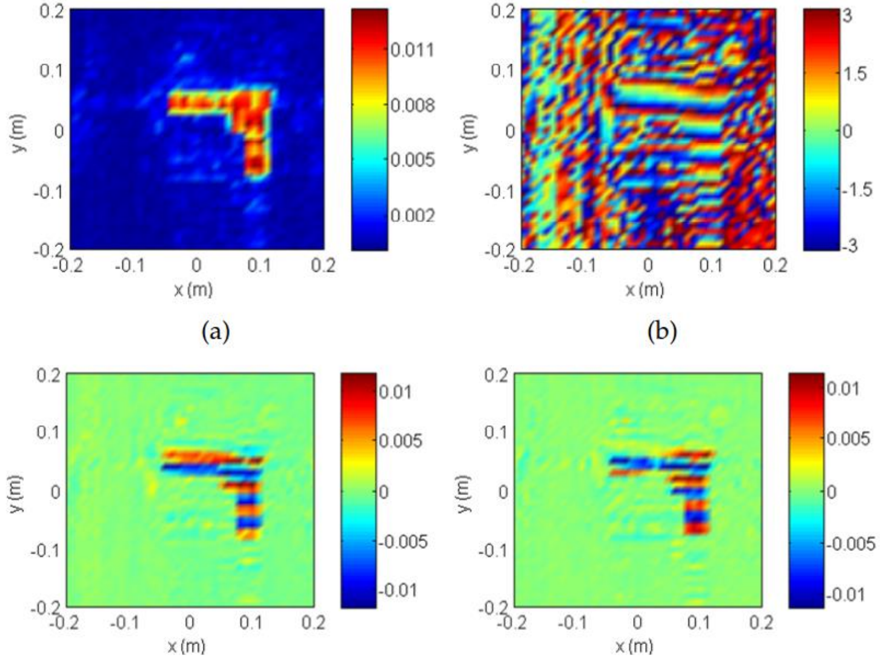


Measuring system

Scanning system

Performance Analysis

Sparsity constraint



(a) (b)

(c) (d)

$$\hat{f} = \underset{f}{\operatorname{argmin}} \|\dot{M}Af - y\|_2 + \alpha[\mathrm{TV}(F_r) + \mathrm{TV}(F_i)]$$

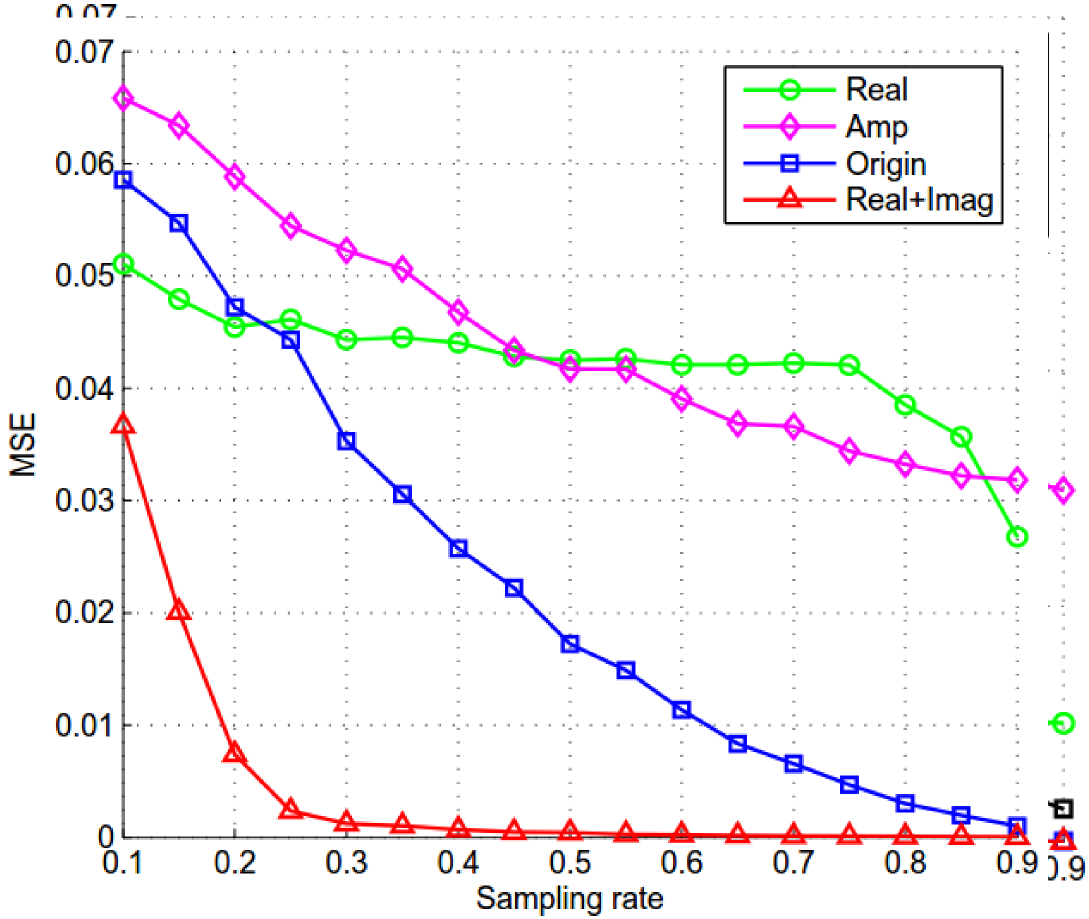
$$f$$

$$\hat{F} = \underset{F}{\operatorname{argmin}} \|M.*HF - Y\|_2 + \alpha[\mathrm{TV}(F_r) + \mathrm{TV}(F_i)]$$

$$\hat{F} = \operatorname{argmin} \|M.*HF - Y\|_2 + \alpha\mathrm{TV}(F)$$
$$\text{where } F = F_r + jF_i$$

Performance Analysis

Sparsity constraint



FT-CS and BP

Performance Analysis

Complexity

Time complexity

D-CS model $\mathcal{O}(KM^2N^2 + KN^2)$

FT-CS model $\mathcal{O}(2M^2 + 4M^2 \log M)$

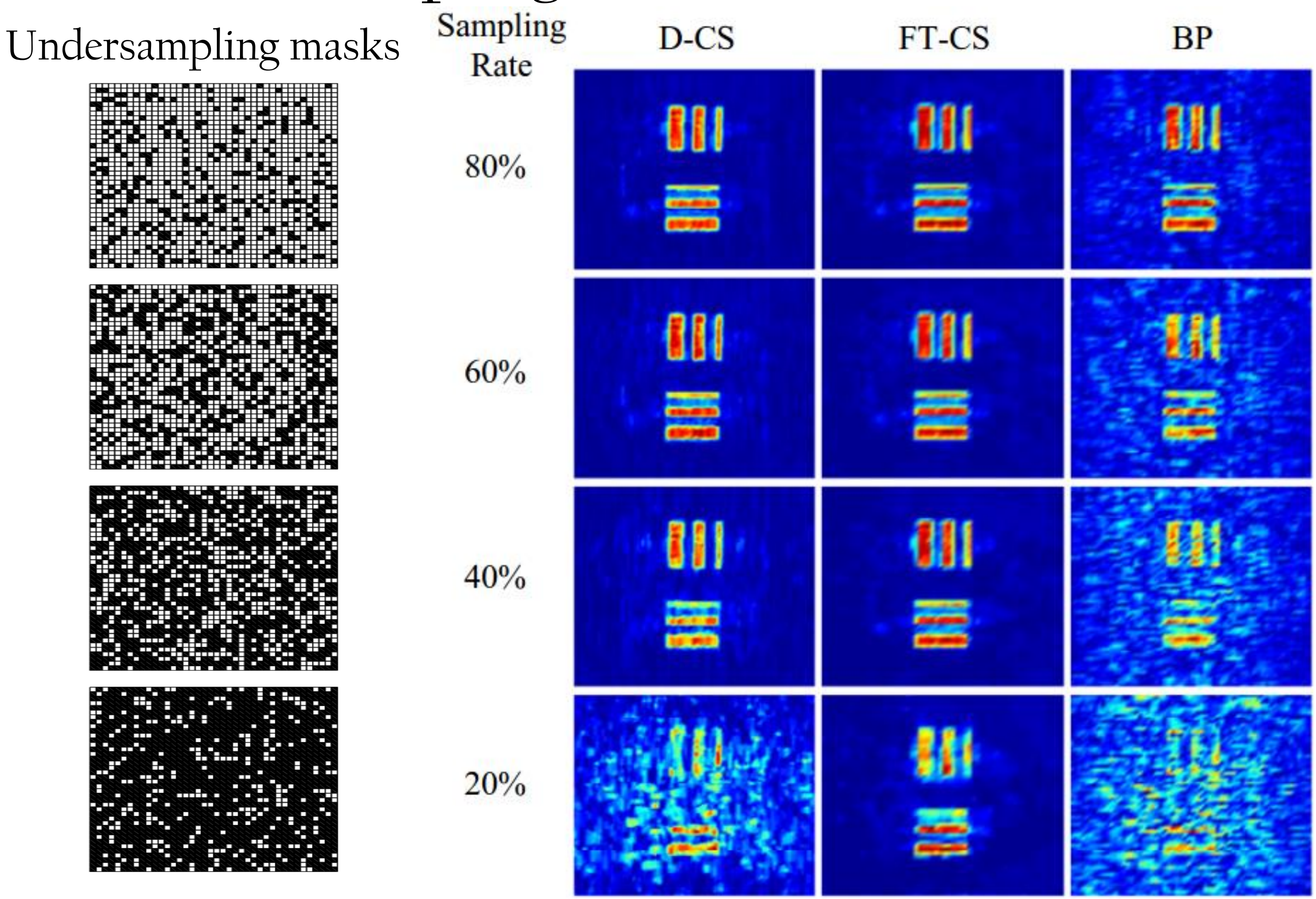
Space complexity

Table 1. Complexity Comparison of D-CS Methods

Configuration	Computing time (s)	Loading time (s)	Storage
$M = 41$, $N = 81$	15.03	1.67	72 MB
$M = 41$, $N = 121$	33.61	3.84	221 MB
$M = 81$, $N = 121$	140.67	17.28	1.04 MB
$M = 81$, $N = 161$	224.36	27.12	1.37 GB
$M = 134$, $N = 134$	1.45×10^3	88.65	2.94 GB
$M = 134$, $N = 178$	4.58×10^3	717.72	8.23 GB

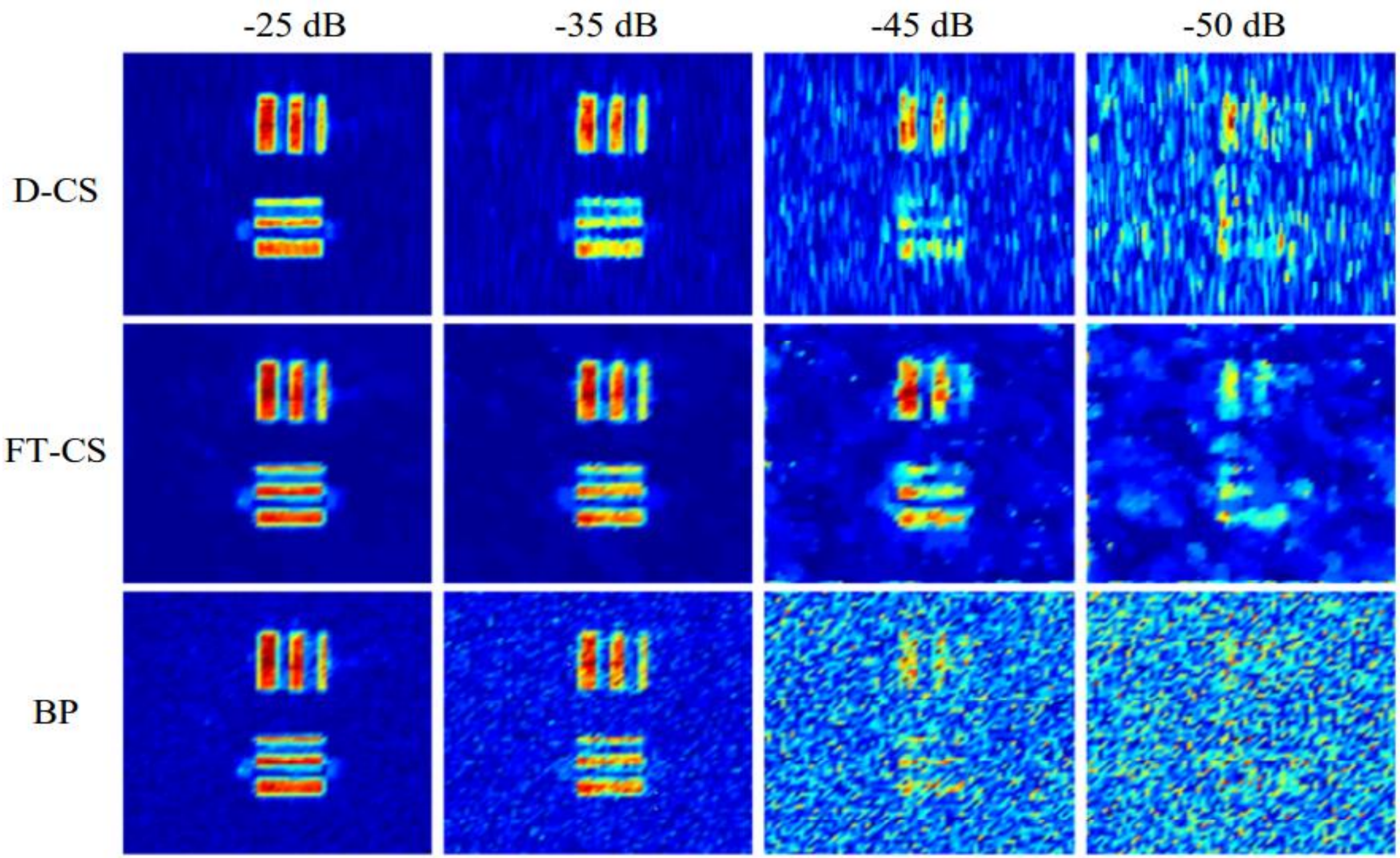
Performance Analysis

Effects of undersampling



Performance Analysis

Effects of background noise



100% sampling rate

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Conclusion

- Sparsity constraint plays an important role in reconstruction.
- The D-CS method achieves the best resolution but requires heavy computation and large number of measurements.
- The FT-CS method does not show much improvement in resolving power. However, it is more robust in many cases.
- Practical imaging systems are suggested to use the D-CS and FT-CS methods jointly.

Thanks