MULTI-SCALE/MULTI-RESOLUTION KRONECKER COMPRESSIVE IMAGING

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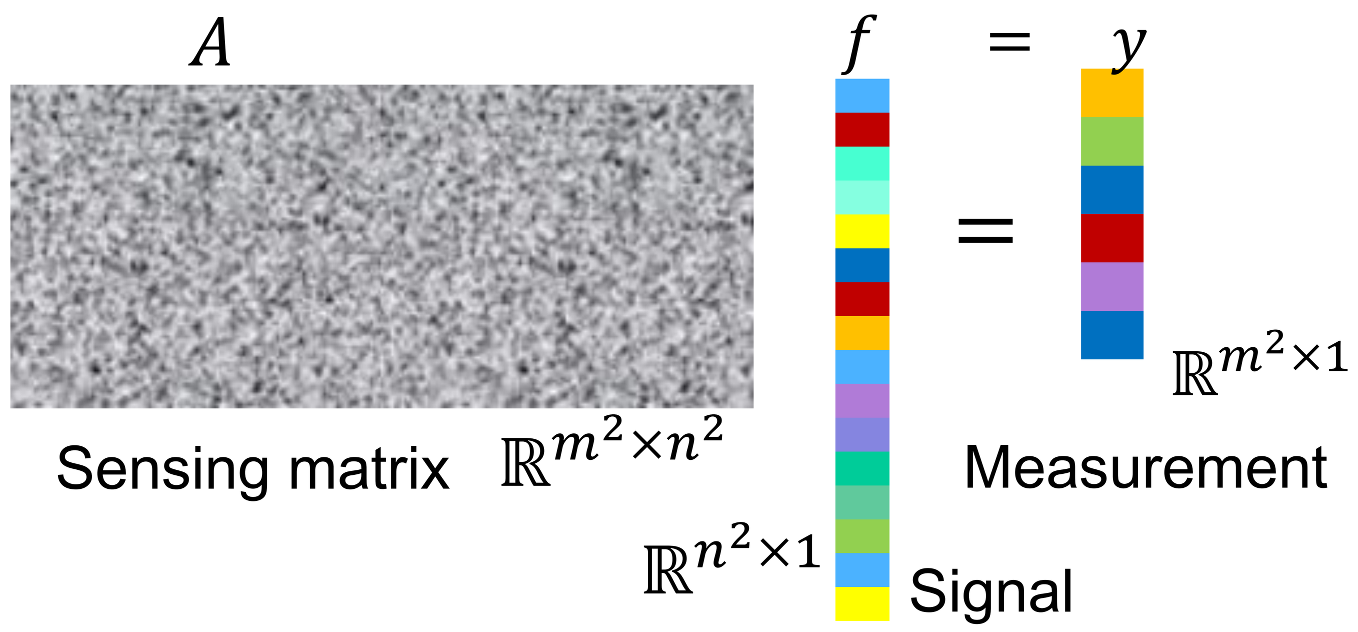
1. Compressive Sensing (CS)



Large size sensing matrix

- High computational complexity
- Large memory requirement

Kronecker CS

- Separate H & V sensing matrices.
- Enable frame based sensing.

$$Y = \Phi^1 F (\Phi^2)^T\ ,\ Y \in \mathbb{R}^{m\times m},$$

$$\Phi = \Phi^1\Phi^2;\quad \Phi^i \in \mathbb{R}^{m\times n},\qquad i = 1,2$$

2. Challenges

Sampling Efficiency

- Conventional CS is universal sampling
  - All CS measurement are equally important.
  - Assumes the sparsity prior only.

Multi-scale sampling is proof as an optimal.

Huge Computational Reconstruction

- The larger resolution, the higher complexity

Multi-resolution sensing is a solution

3. Motivations

- Image prior improves CS's performance
  - Most focus on recover part.
- Image pixel is not equality important
  - Human eye is sensitive to low frequency
  - Each wavelet subband carries different info.
- Multi-resolution is an practical approach
  - Recover low resolution at low cost first
  - Recover high resolution later

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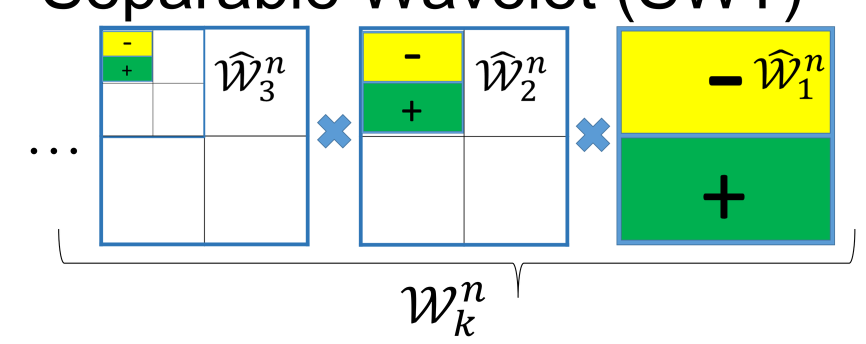
4. Proposed Sensing Matrix

- Separable Wavelet (SWT)



- Block-based KCS

$$\boldsymbol{\Phi}_K^i = \begin{bmatrix} \boldsymbol{\Phi}_0^i & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \boldsymbol{\Phi}_1^i & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \boldsymbol{\Phi}_K^i \end{bmatrix}$$

+/− are low & high pass filter with kernel $1/\sqrt{2}$

- Multi-scale/Multi-resolution measurement

$$Y = \Phi_K^1 (\mathcal{W}_K^n F (\mathcal{W}_K^n)^T)(\Phi_K^2)^T = (\Phi_K^1 \mathcal{W}_K^n) F (\Phi_K^2 \mathcal{W}_K^n)^T$$

Proposed sensing matrix

- Reconstruction at scale q (resolution $n/2^{K-q}$)

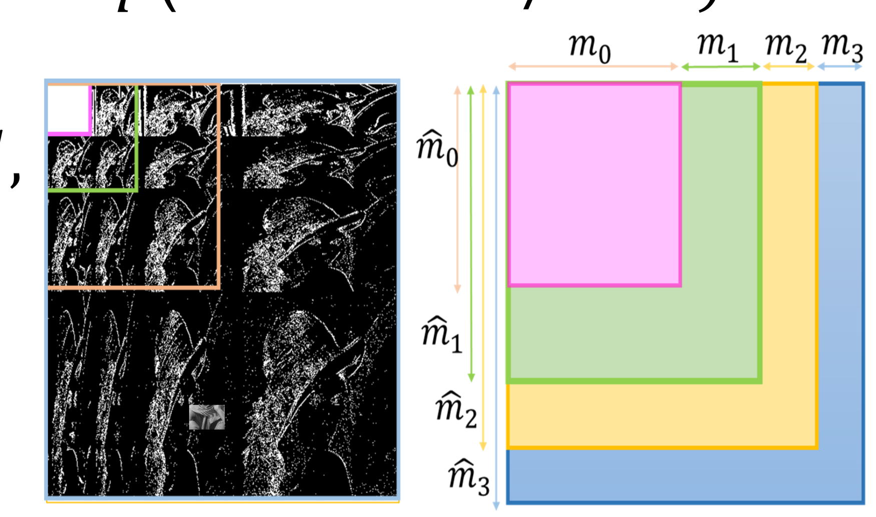
Sensing Matrix

$$\tilde{\Phi}_q^i = (\sqrt{2})^{K-q}\Phi_q^i \mathcal{W}_q^{n_q},\quad i = 1,2$$

Measurement

$$Y_q = \mathrm{Y}(1\!:\!\hat{m}_q, 1\!:\!\hat{m}_q)$$

$$\hat{m}_q = \sum_{j=q}^{1} m_j$$



Binary image of SWT and multi-scale meas. at level 3

5. Proposed Measurement Allocation

Sample more measurement at low SWT subband.

- MRK: Require no prior information

$$\boxed{m_j = \tilde{m}\,\omega_j / 2^{K-j+1}}$$

$$m = m_0 + \sum_{i=1}^{K} m_i = \sum_{i=1}^{K} \tilde{m}\omega_i \frac{1}{2^{K-j+1}}$$

- $\omega_j = a^{K-j}$ is weight ratio with $a = const.$ $m_0 = n/2^K$.

- MRKa: adaptive with sparsity prior
  - SWT sparsity with global threshold
    $$\tau = \lambda\sigma\sqrt{2\log Q},\quad \text{where}\ \ \sigma = \frac{median(|F_K|)}{0.6745}$$
  - Relative local sparsity
    $$s_j = \left\|(F_K)_j\right\|_0 / Q_K$$
    - F_K: SWT transform of F
    - Q_k:the subband size
  - Adaptive meas. $\boxed{m_j = \tilde{m}\,\omega_j s_j / 2^{K-j+1}}$

7. Conclusions

- Our sensing matrix support both multi-scale, multi-resolution and compatible with traditional CS recovery
- Meas. allocation w/wo prior preserve low freq. well
- Enable application for scalable image/video application

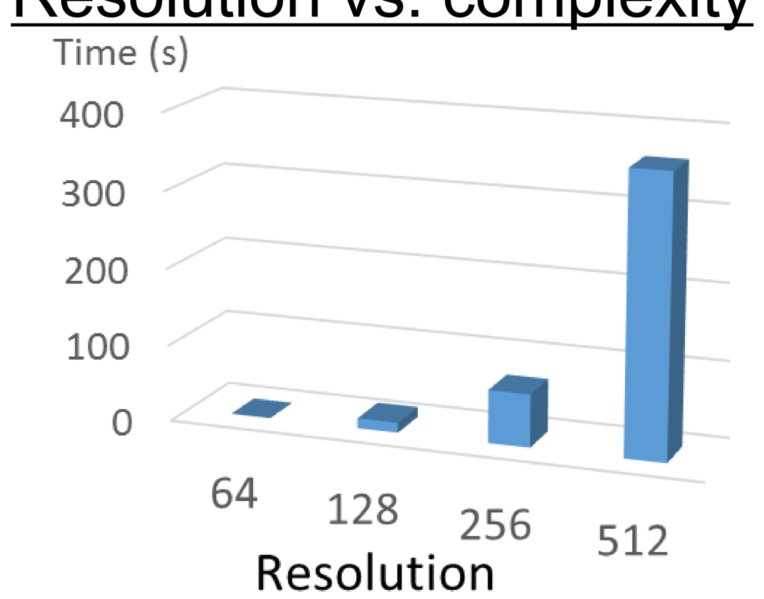
6.Experimental Results

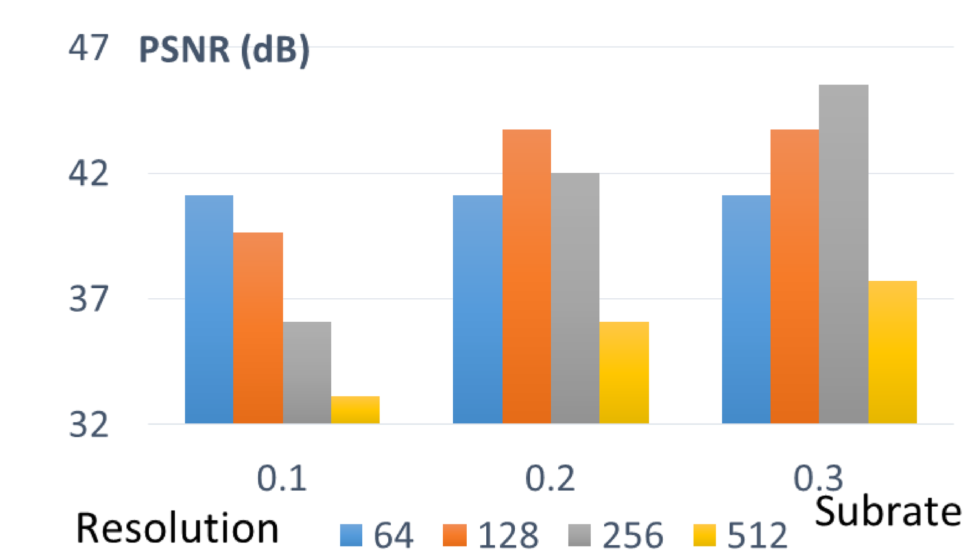
Measurement allocation: MRK vs. MRKa

No. meas.	SR = 0.1			SR = 0.2			SR = 0.3		
	$\mathcal{M}$	$\mathcal{M}a^1$	$\mathcal{M}a^2$	$\mathcal{M}$	$\mathcal{M}a^1$	$\mathcal{M}a^2$	$\mathcal{M}$	$\mathcal{M}a^1$	$\mathcal{M}a^2$
m_0	64	64	64	64	64	64	64	64	64
m_1	56	43	31	64	64	52	64	64	64
m_2	28	41	39	67	75	65	101	113	87
m_3	14	14	28	34	26	48	51	39	65
Total	162			229			280		

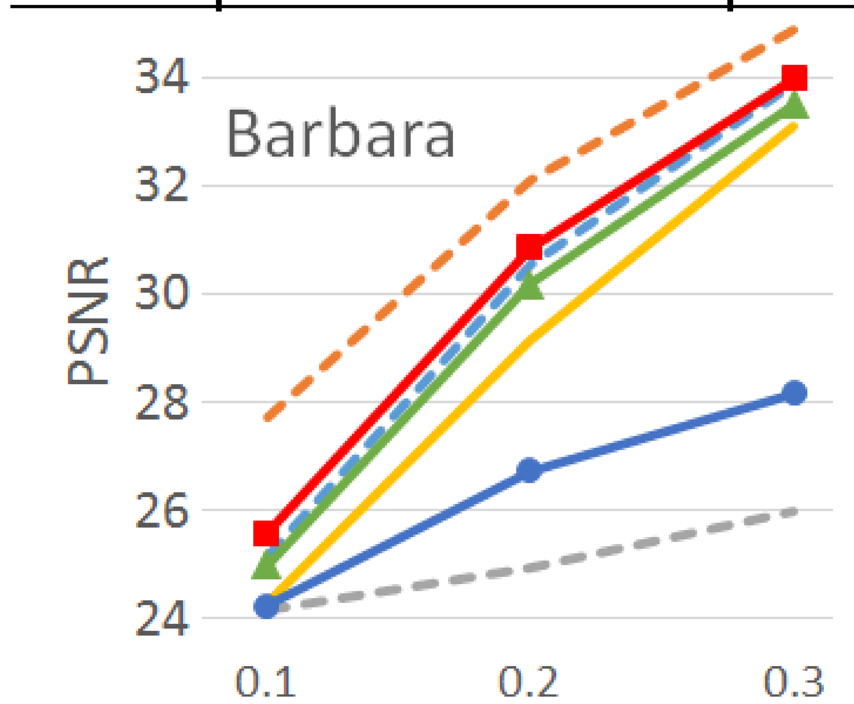
$\mathcal{M}$: using MRK; $\mathcal{M}a^1, \mathcal{M}a^2$ using MRKa for Lena & Barbara

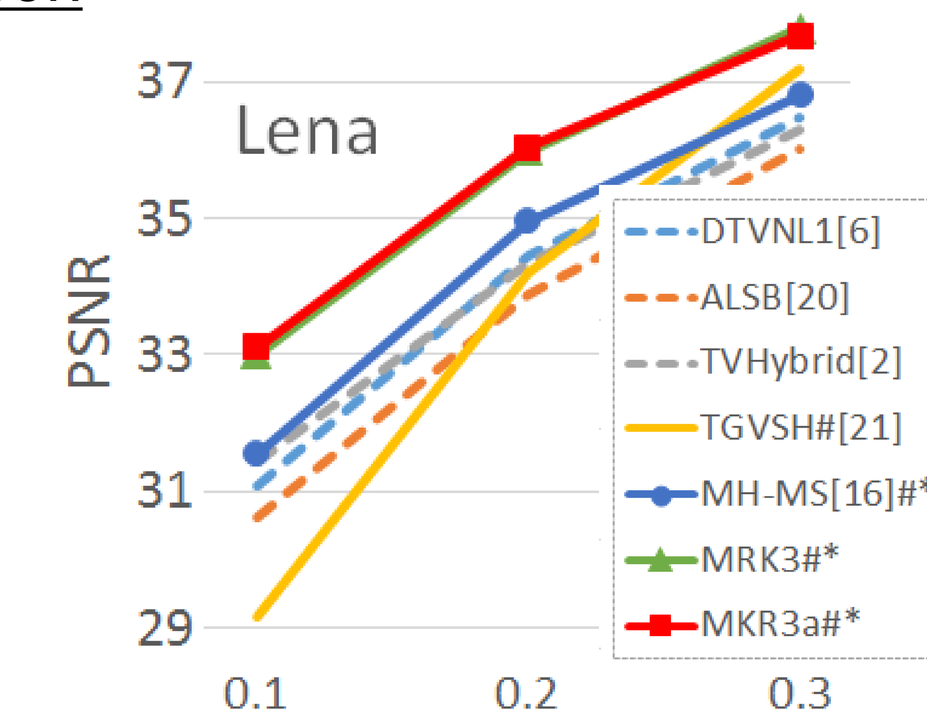
Resolution vs. complexity



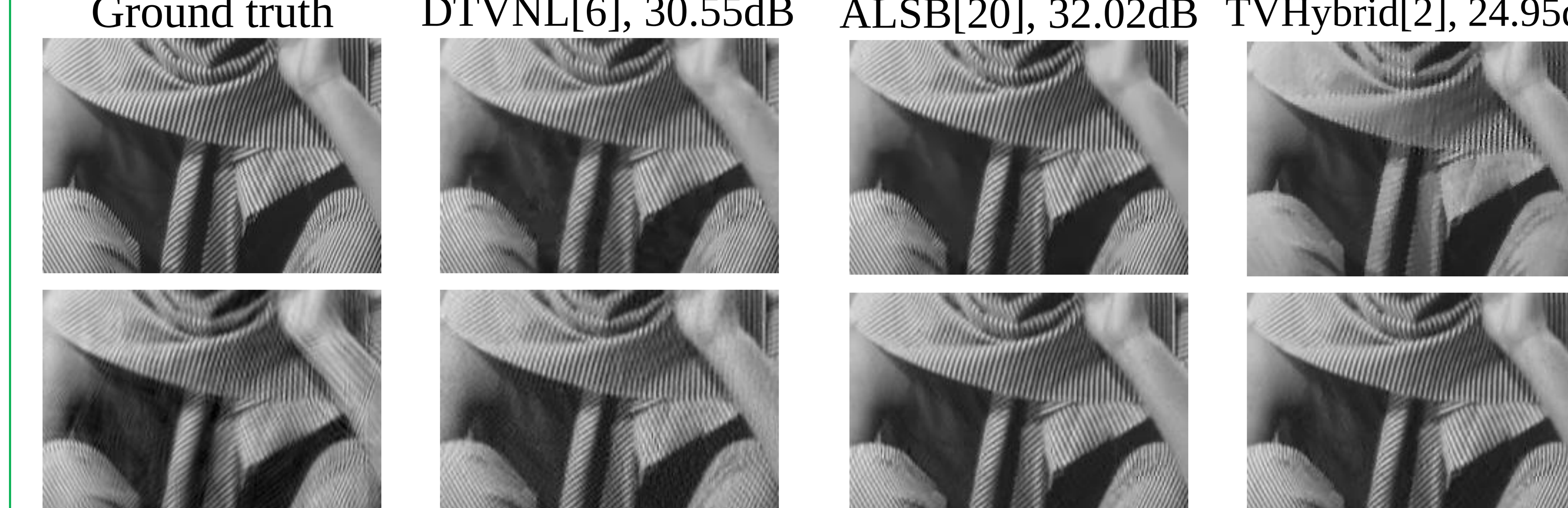


PSNR performance comparison





Visual quality comparison for Barbara image at subrate 0.2



Ground truth | DTVNL[6], 30.55dB | ALSB[20], 32.02dB | TVHybrid[2], 24.95dB

TGVSH[21], 29.1dB | MH-MS[16], 26.78dB | MRK3, 30.05dB | MRK3a, 30.90dB

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