Image Deblurring

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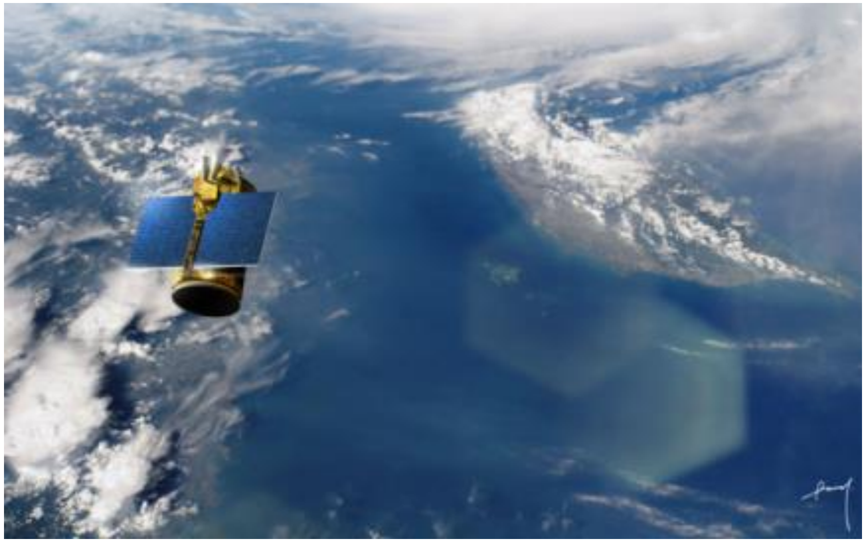


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Problem definition

Blurred image

Latent image

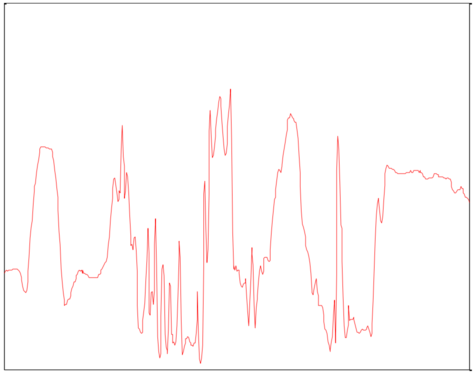
Blur kernel

$$\boldsymbol{B} = I \otimes K + \boldsymbol{n}$$

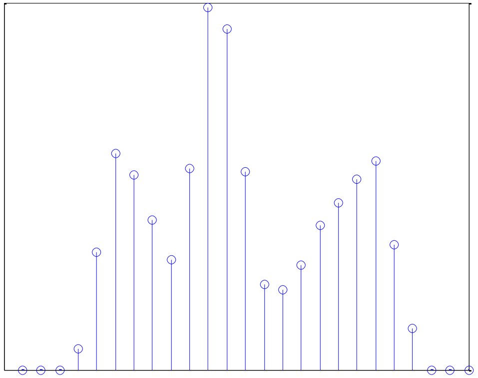
Deblurring: Inverse problem to solve latent ***I*** from given observed noisy ***B*** with (***non-blind***) or without (***blind***) the kernel ***K***

Simple example

Spatial domain



$\otimes$



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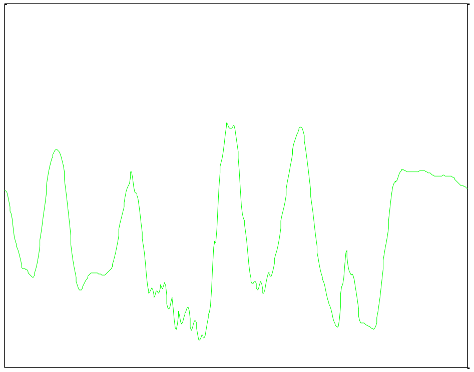
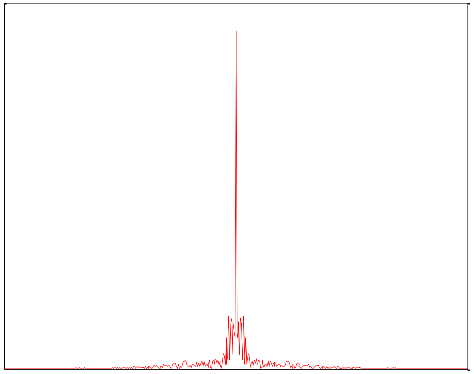


I K B

Simple example

DFT domain (magnitude)



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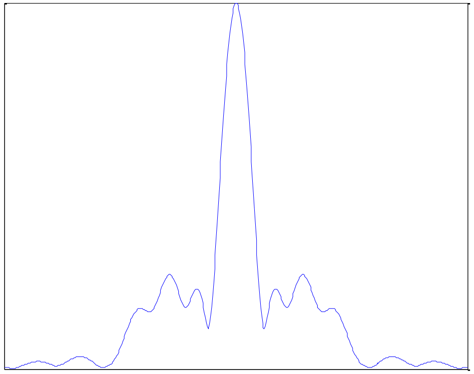

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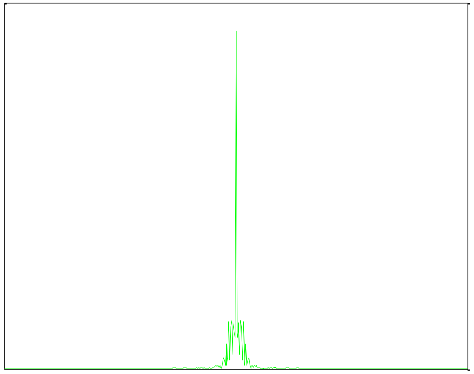
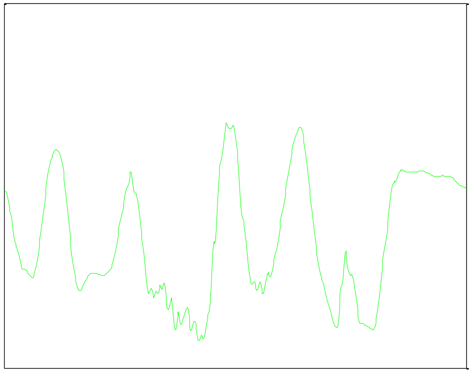
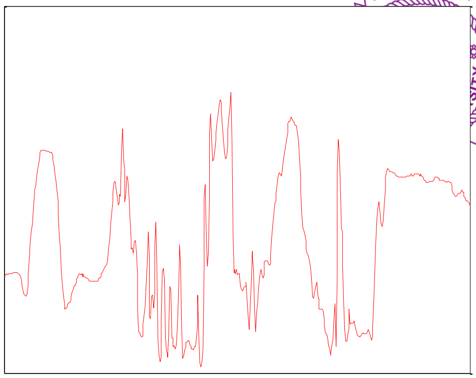


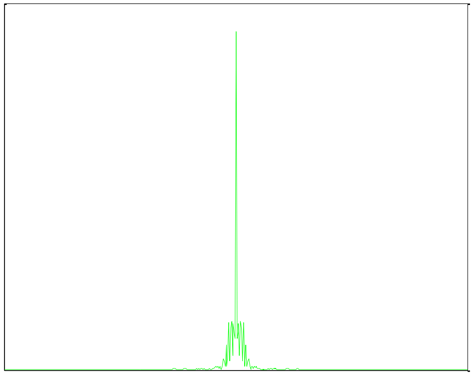
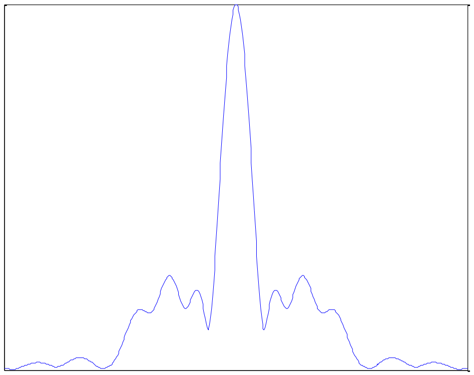
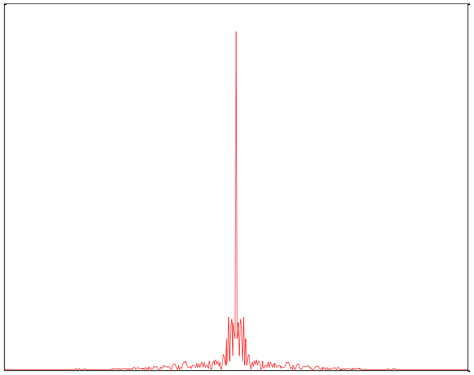
I K $\boldsymbol{B}$



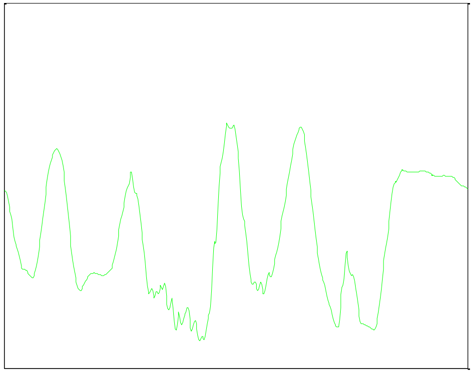
Simple solution?



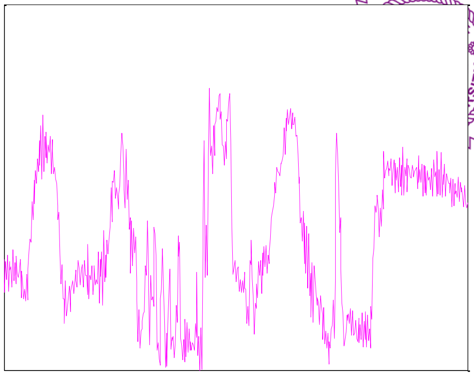
DFT domain (magnitude)

 ÷  = 

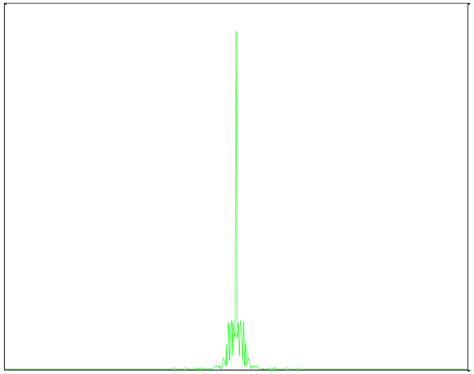
$$\boldsymbol{B} \qquad\qquad K \qquad\qquad \hat{I}$$



Instability



DFT domain (magnitude)



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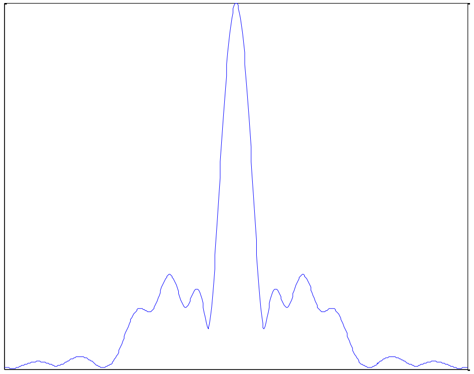

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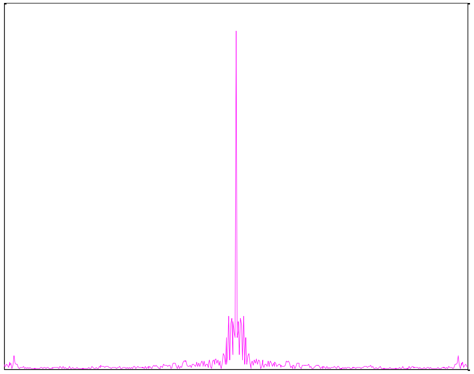
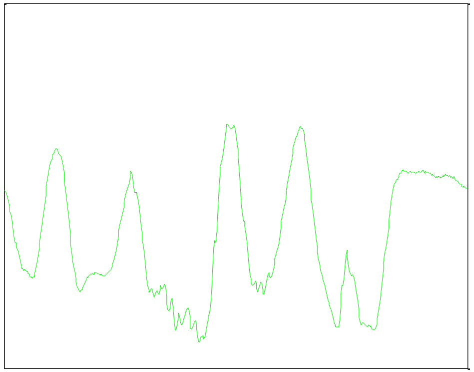


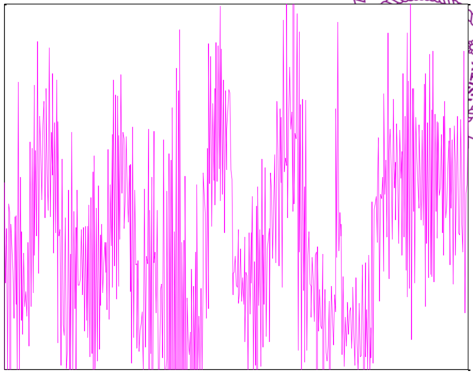
$\boldsymbol{B}$ **(+AWGN** $\sigma = 0.1$**)**

K

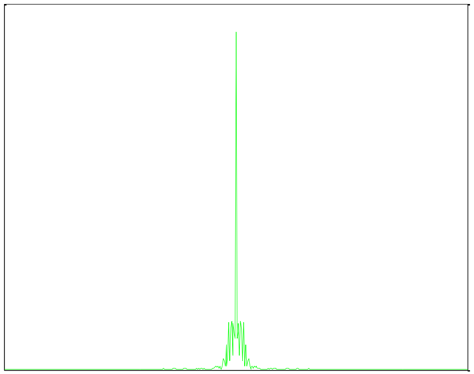
$\hat{I}$



Instability



DFT domain (magnitude)



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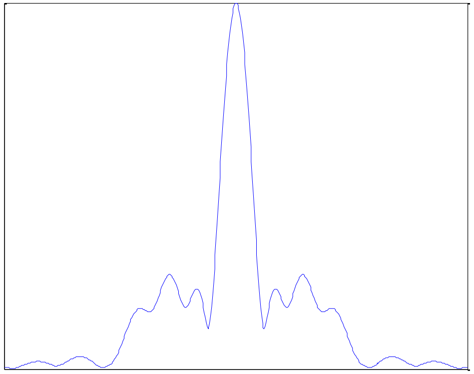

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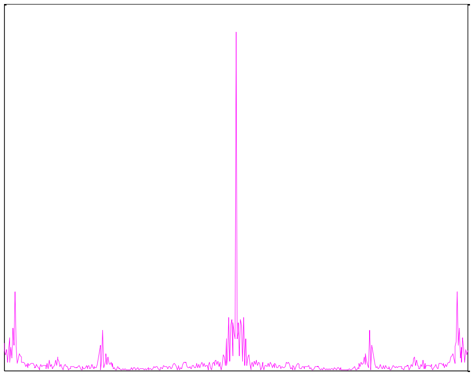


$\boldsymbol{B}$ **(+AWGN $\sigma = 0.5$)**

K

$\hat{I}$

Similar inputs result in different outputs!

Difficulty of deblurring (1/3)

- For non-blind deconvolution (given kernel ***K***)
  - ***K*** may have zeros in magnitude response
    - Some information of ***I*** is gone and can't be recovered
    - *FFT*{***B***}/*FFT*{***K***} will amplify noise at frequencies with zeros
  - Deblurring quality is kernel-dependent
    - Good quality for sharp kernel (e.g. **camera shake**)
    - Blurred result for lowpass kernel (e.g. defocus blur)

Difficulty of deblurring (2/3)

- For blind deconvolution (find the kernel ***K***)
  - Multiple solutions of ***K*** are possible
    - Addressed by prior knowledge (***K*** is sharp)
  - Convolution doesn't hold at saturation regions
  - no information for ***K*** in smooth texture regions

Difficulty of deblurring (3/3)

- Algorithm limit
  - To sum up, deblurring tries to restore the image as sharp as possible, not to recover it exactly
  - Shift-invariant camera shake is the major target here
    - Other blur kernels are more difficult: shift-variant kernel, motion blur, …

Wiener deconvolution

- Wiener filter for each frequency component

$$\hat{I} = B \cdot \frac{1}{K}$$

instable

$$\Rightarrow \quad \hat{I}(f) = B(f) \cdot \frac{1}{K(f)} \left[\frac{|K(f)|^2}{|K(f)|^2 + \frac{1}{\mathrm{SNR}(f)}} \right]$$

I $\quad$ B $\quad$ $\hat{I}$

credit: Wikipedia

Burst deblurring

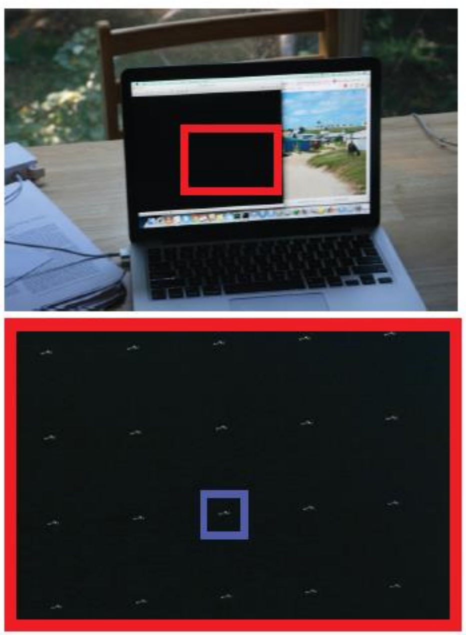
- Accumulation of burst images in Fourier domain
  - **Benefit**: No inverse problem solving
    - e.g. ~~kernel estimation~~, ~~deconvolution~~
  - **Requirement**: Burst image capturing
  - **Assumption**: Kernels in each image are *random*, and each kernel *disperses* the spectrum and preserves energy

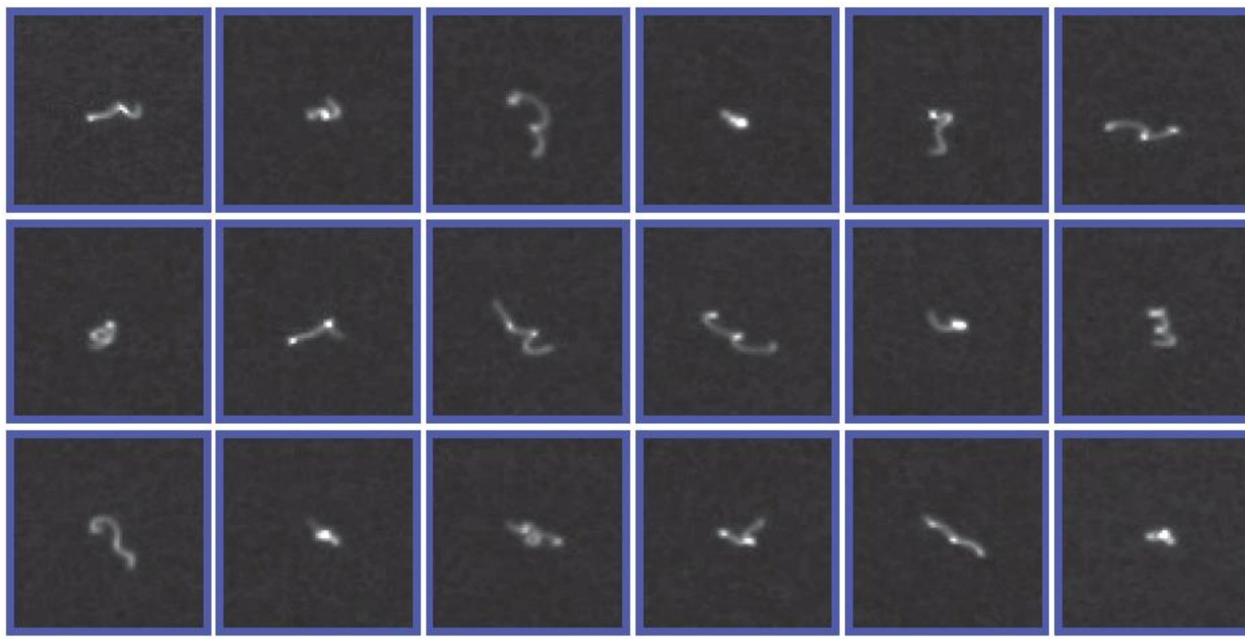
Utilize the random behavior of burst kernels as a deterministic clue to aggregate images.

Ref : M. Delbracio, et. al., “Burst Deblurring: Removing Camera Shake Through Fourier Burst Accumulation,” CVPR’15.

Random nature of hand tremor

- Low correlation between successive frames for low shutter speed
  - Tremor source: arm (<5Hz), wrist (5-20Hz) and fingers (20-30Hz)





Hand tremor in successive shoots

Blurring kernel doesn’t amplify spectrum

$$k(\mathbf{x}) \geq 0 \; and \int k(\mathbf{x}) = 1$$

$$\Downarrow$$

$$\left|\hat{k}(\zeta)\right| = \left|\int k(\mathbf{x}) e^{i\mathbf{x}\cdot\zeta} d\mathbf{x}\right| \leq \int |k(\mathbf{x})| \, d\mathbf{x} = \int k(\mathbf{x}) d\mathbf{x} = 1$$

- The attenuation of each spectrum coefficient is random
- Pick the largest amplitudes cross blurred images to estimate the latent one

$\Rightarrow$ **Fourier burst accumulation!**

Fourier burst accumulation (FBA)

- Perform robust weighted average for each frequency component ζ in Fourier domain

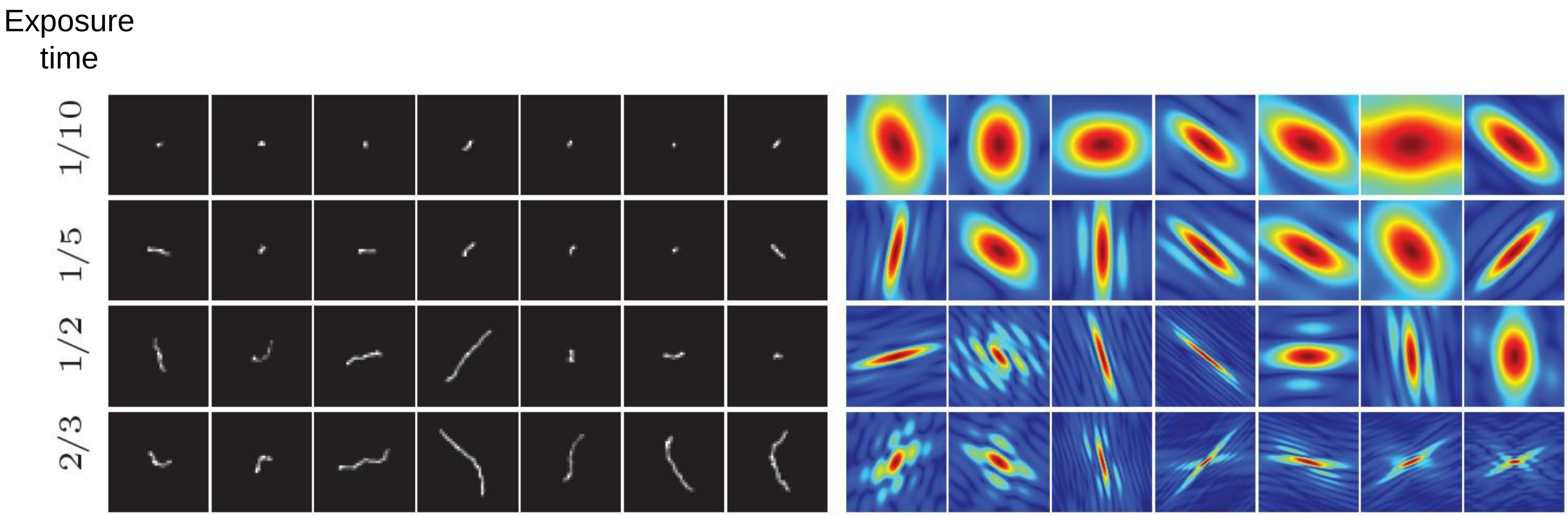
$$u_p(\mathbf{x}) = \mathcal{F}^{-1}\left(\sum_{i=1}^{M} w_i(\zeta)\cdot\hat{v}_i(\zeta)\right)(\mathbf{x})$$

$$w_i(\zeta) = \frac{|\hat{v}_i(\zeta)|^p}{\sum_{j=1}^{M}|\hat{v}_j(\zeta)|^p},$$

Control the accumulation behavior:
$p = 0$: simple average;
$p \to \infty$: maximum pooling.

Behavior of $\hat{k}(\zeta)$

- If hand tremor is random enough, Fourier burst accumulation can cover most of frequency components (red in the below)

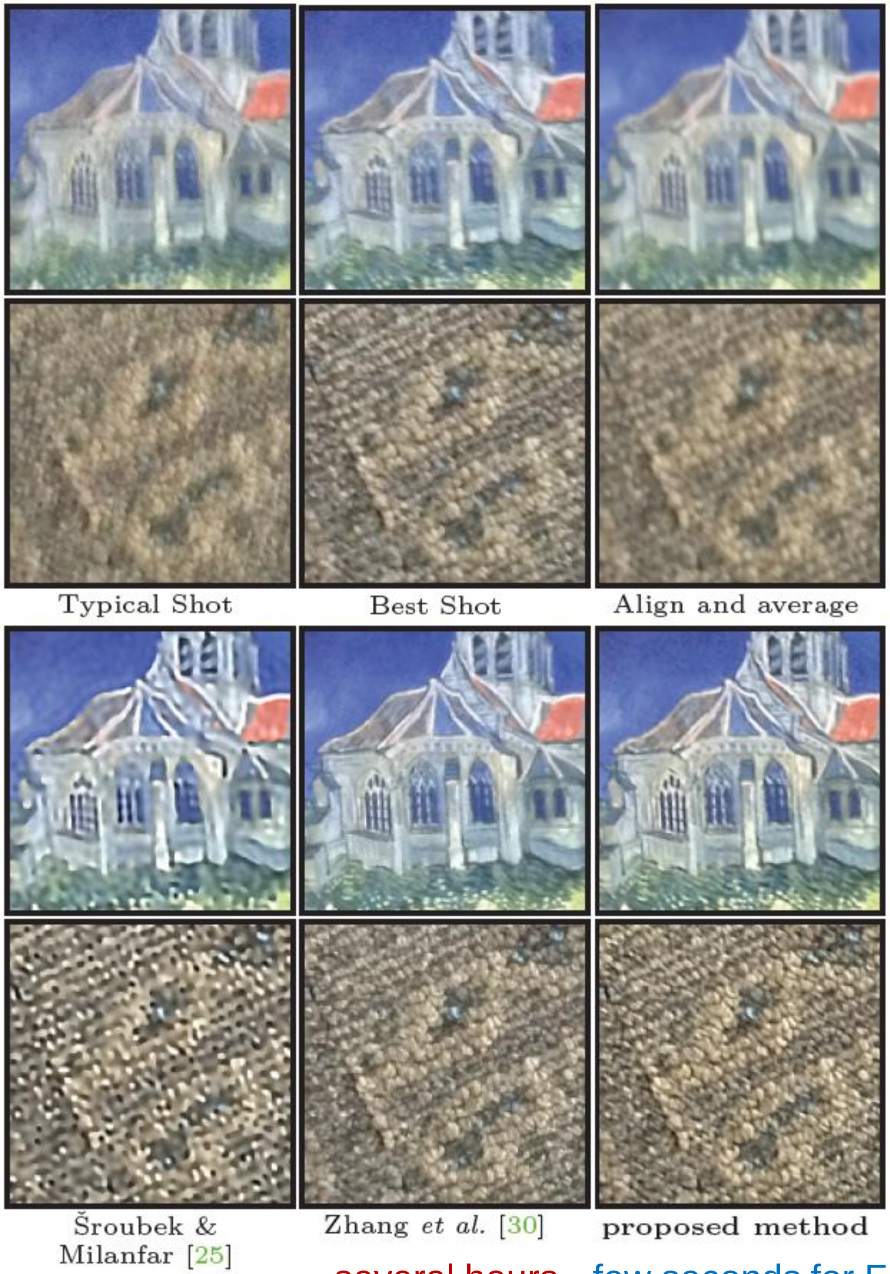


Blurring kernel due to hand tremor

Magnitude response

Experimental results

- 8~13 burst images
- 6~8M pixels



several hours few seconds for FBA

Typical Shot	Best Shot	Align and average	Šroubek & Milanfar [25]	Zhang *et al.* [30]	proposed method (no final sharp.)	**proposed method**