Non-uniform Deblurring for Shaken Images

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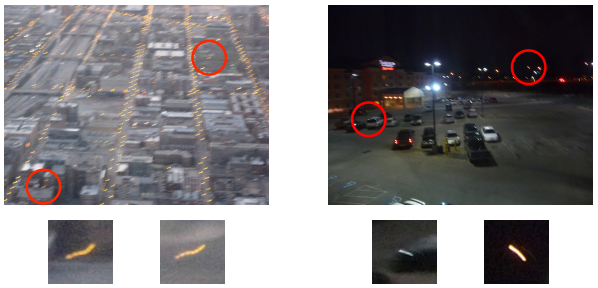
Goal

To model and deblur camera shake images with non-uniform blur



Approximately uniform blur | Non-uniform blur

Both blurs are possible under camera shake

Geometric model

We model the blur as being caused by the 3D rotation of the camera during exposure

Camera orientations: $\boldsymbol{\theta}_0 \cdots \boldsymbol{\theta}_t \cdots \boldsymbol{\theta}_T$ (3-vector)

Rotation matrices: $\mathbf{R}(\boldsymbol{\theta}_t)$ (3 x 3 matrix)

Homographies: $\mathbf{H}_t = \mathbf{K}\mathbf{R}(\boldsymbol{\theta}_t)\mathbf{K}^{-1}$ (camera's internal calibration matrix)

Blurry image is the sum of a sequence of projectively-transformed versions of the sharp image

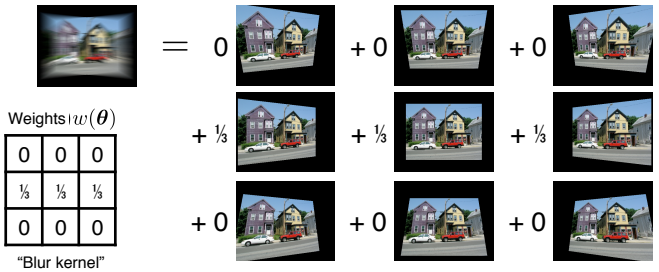
$$\text{blurry image} = \int_0^T \text{sharp image}\ f(\mathbf{H}_t\mathbf{x})\ dt + \varepsilon \quad \text{(noise, homography at time instant } t\text{)}$$

Time-agnostic model

Replace the temporal integral with a weighted integral over a set of camera orientations

$$g(\mathbf{x}) = \int f(\mathbf{H}_{\boldsymbol{\theta}}\mathbf{x}) w(\boldsymbol{\theta})\ d\boldsymbol{\theta} + \varepsilon$$

$f(\mathbf{H}_{\boldsymbol{\theta}}\mathbf{x})$: homography induced at camera orientation $\boldsymbol{\theta}$; $w(\boldsymbol{\theta})$: weight function (non-zero along camera's trajectory); integrate over camera orientations

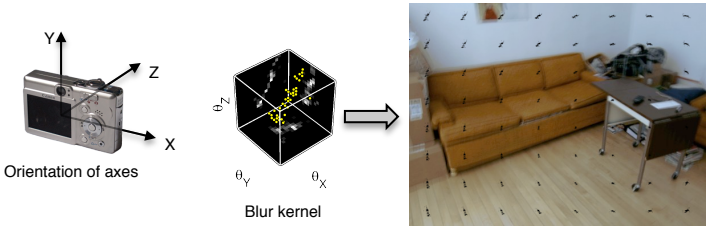


Discrete model

Replace integral with a sum over a discrete set of camera orientations $\boldsymbol{\theta}_k, \quad k \in \{1, \ldots, K\}$

$$g_i = \sum_k f(\mathbf{H}_k\mathbf{x}_i) w_k + \varepsilon = \sum_k \left(\sum_j C_{ijk} f_j \right) w_k + \varepsilon$$

$\mathbf{x}_i$: blurry pixel with homogeneous coordinate vector; w_k: weight for camera orientation $\boldsymbol{\theta}_k$; $f(\mathbf{H}_k\mathbf{x}_i)$: interpolated point in sharp image; C_{ijk}: interpolation coefficients (given by geometry); f_j: sum over sharp pixels



Convolution

$$g_i = \sum_k f_{x_i - u_k, y_i - v_k} w_k + \varepsilon$$

Our model

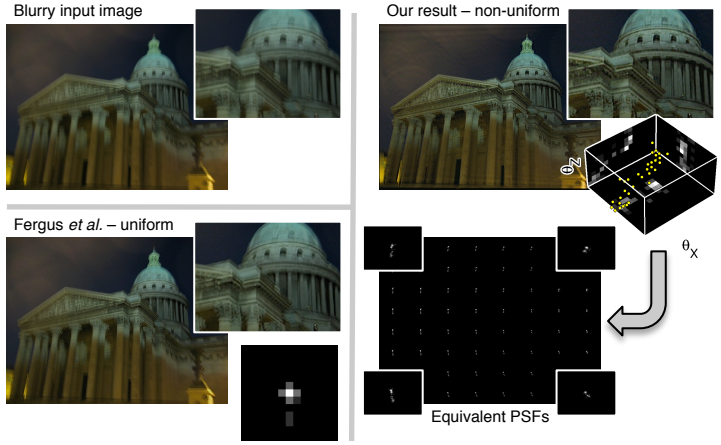
$$g_i = \sum_k \left(\sum_j C_{ijk} f_j \right) w_k + \varepsilon$$

Both are bilinear in the sharp image and the blur kernel

Application I: Blind deblurring

[Fergus *et al.* 2006, Miskin & MacKay 2000]

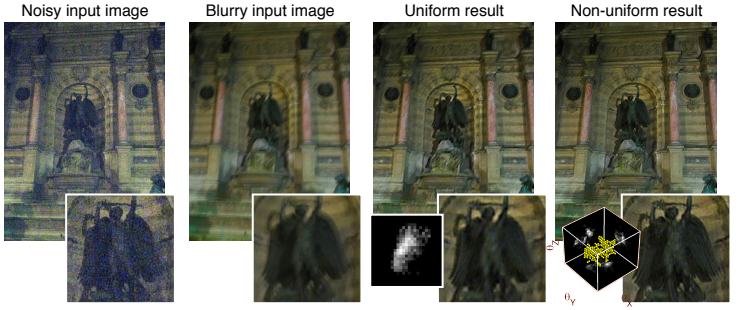
- Kernel estimation: Variational approximation of posterior
- Deblurring: Richardson-Lucy algorithm



Application II: Noisy/blurry pairs

[Yuan *et al.* 2007]

- Kernel estimation: Least squares, using noisy image as estimate of sharp image
- Deblurring: Augmented Richardson-Lucy algorithm, using noisy image to suppress "ringing" artifacts



Conclusion

- Geometrically-derived model of camera shake blur
- Compact, global, representation of blur
- Modification of two existing deblurring algorithms to use our model, allowing them to handle non-uniform blur