Reduction of Poisson noise in coded exposure photography

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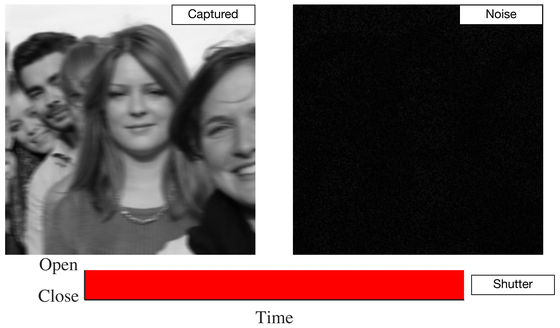
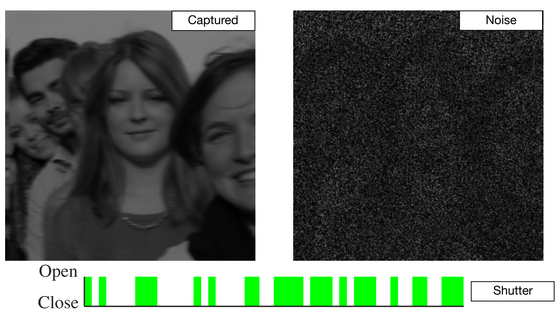
1. Overview

Coded exposure photography [1], originally proposed by Raskar *et al.*, is known as one of promising techniques for motion deblurring. In this are, much efforts [1-2] have been made for designing a fluttered shutter sequence to shape the spectrum of a uniformly motion-blurred image into an invertible one. Since the duty cycle of the fluttered shutters proposed thus far is generally low, the number of photons entering into an image sensor is reduced, which leads to a large Poisson noise. To overcome the difficulty, we propose a new motion deblurring framework using a higher duty-cycle fluttered shutter and a compressive sampling technique [3].

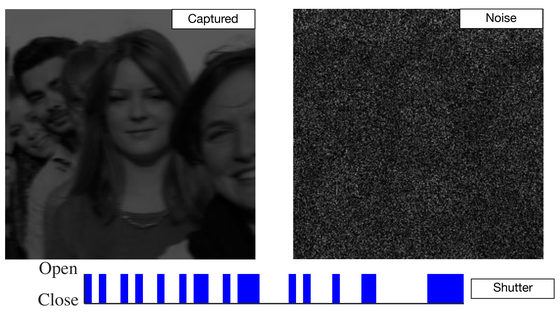
2. Coded Exposure Photography



(a) Conventional (100 %)



(b) Raskar's [1] (50 %)



(c) Jeon's [2] (44 %)

Fig. 1: Captured image, noise, and shutter

- Images captured with a hand-held camera are often degraded by a motion blur in a long exposure time.
- The ideal and captured images, f and g, respectively, are related by a convolution as

$$g_{i,j} = (f \star p)_{i,j} + n_{i,j}, \quad i,j = 0, ..., N-1$$

n: An additive Gaussian noise of mean 0 and std. dev. σ.
p: The impulse response representing motion blur.

- We try to restore unknown f from g and **known** p.
- One of motion deblurring techniques is

$$\hat{f}_{u,v} \simeq \hat{g}_{u,v} \,/\, \hat{p}_{u,v}, \quad u,v = 0, ..., N-1$$

$\hat{g}, \hat{p}$: The discrete Fourier transforms (DFTs) of g and p.

- f can be approximately recovered via the inverse DFT.
- $\hat{p}$ may have some zeros leading to singularities of $1 \,/\, \hat{p}$.
- Ref. [1] proposed the coded exposure photography.
- A fluttered shutter (FS) has been introduced.
- The FS is designed in such a way that $\hat{p}$ has no zeros.
- The DFT technique is always feasible.
- The duty cycle of the FS are generally low.
- The number of photons entering into an image sensor decreases.
- The captured images suffer from Poisson noise.
- The DFT technique amplifies both G. n. and P. n..

3. Proposed Technique

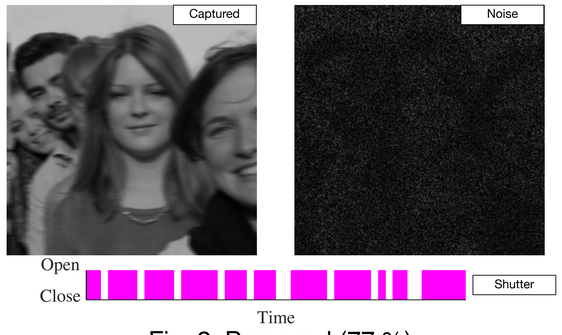


Fig. 2: Proposed (77 %)

- We introduce a higher duty-cycle (77 %) FS.
- Zeros and near-zeros amplify the DFTs of noise.
- We exploit a compressive sampling (CS) technique [3].
- The ideal image can be recovered from partial DFT:

$$\min_{z \in \mathbb{R}^{N \times N}} \mu \|z\|_{\mathrm{TV}} + \frac{1}{2} \sum_{(u,v) \in \Omega} \left(\hat{z}_{u,v} - \hat{f}_{u,v} \right)^2$$

$$\hat{f}_{u,v} = \hat{g}_{u,v} / \hat{p}_{u,v} \text{ and } \Omega = \left\{ (u',v') \,\middle|\, |\hat{p}_{u',v'}| \geq \tau \right\}$$

μ : Regularization parameter. τ : Threshold value.

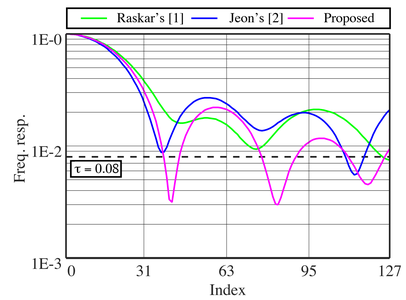


Fig. 3: Freq. resp. of each coded blur

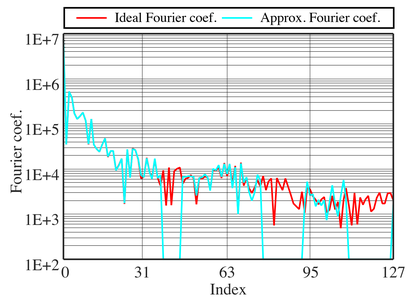


Fig. 4: Ideal / approx. Fourier coef.

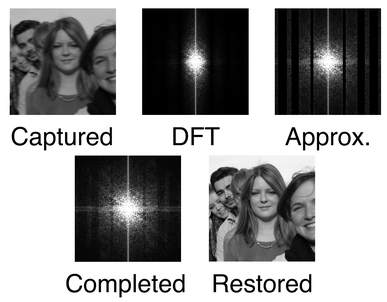


Fig. 5: Overview of CS deblurring

4. Experimental Results

Fig. 6: Restored images with and without P. n.

$N = 256$, μ=10, $\tau = 0.08$, $\sigma = 0.5$, P. n. param. 0.01, 7 pels horizontal blur

5. Summary

- Higher duty-cycle FS.
- CS-based deblurring.
- How do we select τ ? (Future work)
- For coded aperture ? (Future work)

6. References

[1] R. Raskar, A. Agrawal, and J. Tumblin, "Coded exposure photography: motion deblurring using fluttered shutter," *ACM Transactions on Graphics*, vol. 25, no. 3, pp. 795-804, 2006.

[2] H. G. Jeon, J. Y. Lee, Y. Han, S. J. Kim, and I. S. Kweon, "Fluttering pattern generation using modified Legendre sequence for coded exposure imaging," in *Proceedings of IEEE International Conference on Computer Vision*, 2013.

[3] C. Poon, "On the role of total variation in compressed sensing," *SIAM Journal on Imaging Science*, vol. 8, no. 1, pp. 682-720, 2015.