Image Pre-Compensation: Balancing Contrast and Ringing

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Overview

Input: A sharp image I and a (blur) kernel K

Output: A ***pre-compensated image*** J so that

$$J \ddot{A} K = I$$

Applications

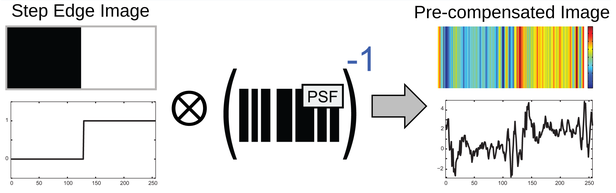
- Compensate for projector defocus.
- Improve visual acuity.

Naïve Solution: $J = I \ddot{A} K^{-1}$

Previous Approaches

- Wiener filter [1], steepest descent [2], etc.
- Only effective on small blur kernels.

The Dynamic Range Problem



- J has very high dynamic range.
- Dynamic range compression (f) is needed:

$$f(J) \ddot{A} K = J_f \ddot{A} K = I_f$$

- I_f is very different from I under common tone mapping functions.

Our Solution:

- Contrast-priority tone mapping scheme for balancing contrast and ringing.

Contrast vs. Ringing

Linear Compression Function l

$$J_l = l(J) = \frac{J - \min(J)}{r} \xrightarrow{\otimes K} I_l = \frac{J - \mu}{r}$$

where $r = \max(J) - \min(J)$, μ is a constant.

- Contrast loss: $\zeta(I_l) = c(I_l)/c(I) = 1/r$

Non-Linear Compression

- High frequencies non-linearly scaled.
- Contrast enhanced, but has strong **ringing artifacts**.

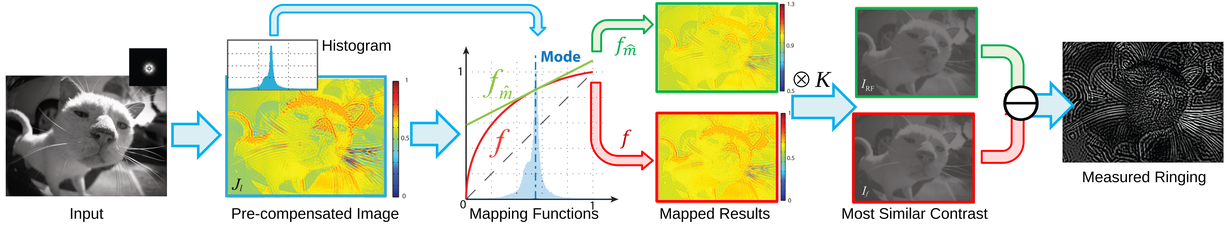
Disambiguate Contrast from Ringing

- Traditional RMS contrast is not good enough:

c= 0.05 c= 0.064

$$c = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(I(i) - \bar{I})}$$

- Measure contrast using "Equivalent Ringing Free Image" (I_{RF})
- Measure ringing as $\Gamma = \| I_f - I_{RF} \|$:



Contrast-Priority Tone Mapping

Tone Mapping Curve Construction

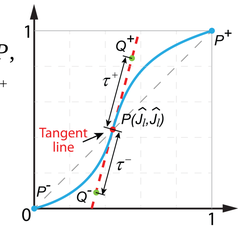
- **Goal:** construct tone mapping function s to produce desired contrast.
- Contrast determined by slope at histogram mode $P = (\hat{J}_l, \hat{J}_l)$.
- Construct "S" shape function using two Bézier segments (B^+ & B^-).

$$\begin{cases} B^-(t) = (1-t)^2 P^- + 2(1-t)tQ^- + t^2 P, \\ B^+(t) = (1-t)^2 P + 2(1-t)tQ^+ + t^2 P^+ \end{cases}$$

where $0 \le t \le 1$

$$Q^- = (\hat{J}_l - \tau^- \sin\theta, \hat{J}_l - \tau^- \cos\theta),$$

$$Q^+ = (\hat{J}_l + \tau^+ \sin\theta, \hat{J}_l + \tau^+ \cos\theta)$$



- Fix slope at P to maintain contrast.
- Adjust curvature (τ^+ & τ^-) to control ringing.

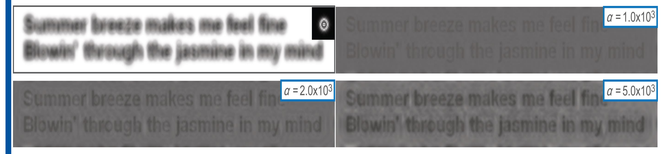
Balance Contrast and Ringing

- Find function that produces similar result to I_{RF}:

$$O(\tau^-, \tau^+; m) = \| I_{RF}(m) - I_s(\tau^-, \tau^+; m) \| + \alpha \frac{1}{m}$$

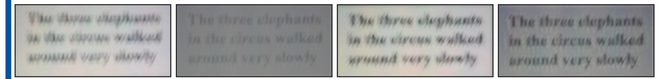
- Use α to balance ringing and contrast.
  - Larger α ⇒ more contrast and ringing

Results



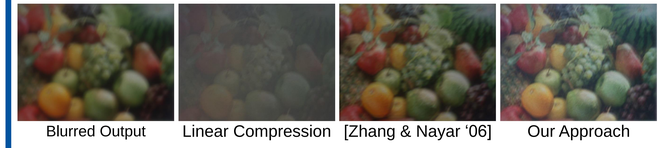
Projector Defocus Compensation

- Grayscale Texts



Blurred Output | Linear Compression | [Zhang & Nayar '06] | Our Approach

- Color Images



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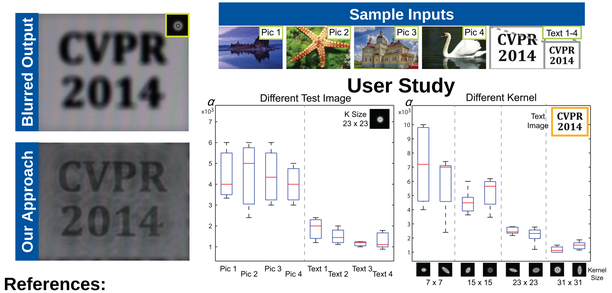
Improve Visual Acuity

- Reading without glasses.



References:

[1] M. S. Brown, P. Song, and T.-J. Cham. Image Pre-Conditioning for Out-of-Focus Projection Blur. CVPR 2006.

[2] L. Zhang and S. K. Nayar. Projection Defocus Analysis for Scene Capture and Image Display. Siggraph 2006.