Inverse Optics (Displays)

CS635 Spring

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• Image Blurring Primer
• PSF and MTF
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• What can you do?
  – Lets look into options
Where does blur come from?
- Optical blur: camera is out-of-focus
- Motion blur: camera or object is moving

Why do we need deblurring?
- Visually annoying
- Wrong target for compression
- Bad for analysis
- Numerous applications
Optical Example

Before

After
Example

Observed image of Saturn → Restored image
Example
Modeling Blurring Process

\[ x(m,n) \rightarrow h(m,n) \rightarrow y(m,n) \]

- \( h(m, n) \) = blurring filter (or kernel, or PSF)
- \( w(m, n) \sim N(0, \sigma_w^2) \) = additive white Gaussian noise
Classic Example

\[ x(m,n) \rightarrow \text{(horizontal blur)} \rightarrow y(m,n) \]
Types of “Deblurring”

• **Blind Deblurring**
  – Blurring kernel unknown

• **Non-blind Deblurring**
  – Blurring kernel known

• **Bounded vs Nonbounded Deblurring**
  – If bounded, pixel values are kept in a fixed range (less studied)
Gaussian filter can be used to approximate out-of-focus blur
Blurring Filter Example

Motion blurring along a line

MATLAB code: h=FSPECIAL('motion',9,30);
Inverse Filter

To compensate the blurring, we seek

\[ h_{\text{combi}}(m,n) = h(m,n) \otimes h^I(m,n) = \sum_{k=-\infty}^{\infty} \sum_{l=-\infty}^{\infty} h^I(m-k, n-l)h(k,l) = \delta(m,n), \quad \forall (m,n) \]

\[
H^I(w_1, w_2) = \frac{1}{H(w_1, w_2)}
\]
PSF and MTF

- PSF (models “blurring” effect and more)

- MTF (shows what the PSF is causing)
Problem: Zeros

\[ OTF = \frac{H(w_1, w_2)}{H(0,0)} \]

\[ MTF = |OTF| \]
Problem: Zeros

\[ OTF = \frac{H(w_1, w_2)}{H(0,0)} \]

\[ MTF = |OTF| \]

The kernel/filter cancels some frequencies and causes “zeroes” which is bad – cannot recover
But It Can (Kinda) Work...

- Some approaches:
  - Inverse Filter
  - Wiener Filter
  - Lucy Richardson

- See Deblurring Tutorial
What can you do to “avoid the zeros”?

• “Flutter the shutter”
  – Raskar et al. 06, Agrawal and Xu ‘09

• View-dependent displays
  – Pamplona et al. 2012

• Multi-layer (additive) displays
  – Huang et al. 2014

• Constrained spatial modulation
  – Montalvo et al. 2015

• Spectral Remapping
  – Oliveira et al. 2017

• What next?
Flutter the Shutter


- See other slides

Figure 1: Coded exposure enables recovery of fine details in the deblurred image. (a) Photo of a fast moving vehicle. (b) User clicks on four points to rectify the motion lines and specifies a rough crop. (c) Deblurred result. Note that all sharp features on the vehicle (such as text) have been recovered.
View-Dependent Displays


Figure 11: How an astigmatic subject sees the green square (a) without correction (c) and with tailored correction (d). (b) shows how a non-astigmatic subject would see the same square. The light field for these pictures is shown on (c), not corrected on left and tailored on the right side. Pinnholes in red. Notice how the pattern deforms under each pinhole. Astigmatic wavefront map has aberrations of 1D in cylinder at the 180-degree meridian (28 < j < 40cm). While an emmetropic view sees the effects of astigmatism (c), an 1D astigmatic view perceives a corrected image (d). Here t = 47 cm. Resolution of 1.16 arc minutes.

Figure 12: Input images (a) and how they are perceived on a tailored display by a farsighted subject (c). The HMD prototype was placed t = 20 cm from the eye (camera). The camera simulated a subject whose closest focal point is j = 50 cm (subject using +3D lenses). Picture (b) shows how the subject sees the respective image on (a), with same size, at the same distance in a standard monitor. Since our setups have small spatial resolution, we mimicked an array of LCDs by changing the image being displayed to cover a bigger “retinal” area. (b) is a collage (sum) of 64 square patches which create a 3.4 arc-minute image on the retina (each path = 0.425 arc minutes). The blue channel of (c) was adjusted to 75% of its captured intensity to remove prototype light leaking.

6 Prototypes and Evaluations

Our dual-stack-LCD prototype uses components from an InFocus
Multi-layer Displays

Constrained Spatial Modulation

Spectral Remapping

- [https://www.inf.ufrgs.br/~eslgastal/SpectralRemapping/](https://www.inf.ufrgs.br/~eslgastal/SpectralRemapping/)

Fig. 1. Comparison of various image-downscaling techniques. (left) Reference image. (right) Downscaling to 180 × 144 pixels performed with: (a) Lanczos filtering followed by resampling using a cubic B-Spline causes structured high-frequency details from the pants, scarf, books, and most of the table cloth to be removed. (b) The technique by Oztieli and Gross introduces aliasing artifacts in those regions. (c) The technique of Weber et al. removes most of these high-frequency details, but still exhibits aliasing (e.g., see books). (d) By remapping high frequencies to the representable range of the downscaled spectrum, our approach retains the structured details. The green plots under the images are the intensity values of the highlighted pixels. The light-blue envelopes show the horizontally-compressed plot of the reference image. "Barbara" test image attributed to Allen Gersho (public domain). Please zoom in to see the details.
What next?