CS354 Computer Graphics
Computational Photography II

Qixing Huang
April 25th 2018
Image and Depth from a Conventional Camera with a Coded Aperture
Levin et al. (SIGGRAPH 2007)
Image and Depth from a Conventional Camera with a Coded Aperture
Levin et al. (SIGGRAPH 2007)
Lens and Defocus

Lens’ aperture

Image of a point light source

Lens

Camera sensor

Focal plane
Lens and Defocus

Lens’ aperture

Image of a defocused point light source

Object

Lens

Camera sensor

Focal plane

Point spread function
Lens and Defocus

Lens’ aperture

Image of a defocused point light source

Object

Focal plane

Camera sensor

Point spread function
Lens and Defocus

Lens’ aperture

Image of a defocused point light source

Object

Lens

Camera sensor

Focal plane

Point spread function
Lens and Defocus

Lens’ aperture

Image of a defocused point light source

Object

Lens

Camera sensor

Focal plane

Point spread function
Depth and defocus

Depth from defocus:
Infer depth by analyzing local scale of defocus blur

Out of focus

In focus
Key contributions

• Exploit prior on natural images
  – Improve deconvolution
  – Improve depth discrimination

• Coded aperture (mask inside lens)
  – make defocus patterns different from
  – natural images and easier to discriminate
Defocus as local convolution

Calibrated blur kernels at different depths
Defocus as local convolution

Input defocused image

Local sub-window

Calibrated blur kernels at depth $k$

Sharp sub-window

Depth $k=1$: 

Depth $k=2$: 

Depth $k=3$: 

$\text{Defocus as local convolution}$
Overview

Try deconvolving local input windows with different scaled filters:

Somehow: select best scale.
Overview

Try deconvolving local input windows with different scaled filters:

Somehow: select best scale.

Challenge: smaller scale not so different than correct.
Coded Aperture

- Mask (code) in aperture plane
  - make defocus patterns different from
  - natural images and easier to discriminate
Solution: lens with occluder
Solution: lens with occluder

Aperture pattern

Image of a defocused point light source

Object

Lens with coded aperture

Camera sensor

Focal plane

Point spread function
Solution: lens with occluder

Aperture pattern

Image of a defocused point light source

Object

Lens with coded aperture

Camera sensor

Point spread function

Focal plane
Solution: lens with occluder

Aperture pattern → Image of a defocused point light source

Object → Lens with coded aperture → Camera sensor

Focal plane
Solution: lens with occluder

Aperture pattern

Image of a defocused point light source

Object

Lens with coded aperture

Camera sensor

Focal plane
Solution: lens with occluder

Aperture pattern

Lens with coded aperture

Image of a defocused point light source

Object

Lens with coded aperture

Camera sensor

Focal plane

Point spread function
Why coded?

Coded aperture - reduce uncertainty in scale identification

Conventional

Coded

Larger scale

Correct scale

Smaller scale
Filter Design

Analytically search for a pattern maximizing discrimination between images at different defocus scales (*KL-divergence*).

Account for image prior and physical constraints.
Regularizing depth estimation

Try deblurring with 10 different aperture scales

\[ x = \arg \min f \otimes x - y + \lambda \sum_i \rho(\nabla x_i) \]

Keep minimal error scale in each local window + regularization
Local depth estimation

Regularized depth
Computational Illumination
Digital Photography with Flash and No-Flash Image Pairs
Petschnigg et al. (SIGGRAPH 2004)

Flash	No-Flash
Digital Photography with Flash and No-Flash Image Pairs
Petschnigg et al. (SIGGRAPH 2004)
The Dilemma: to Flash or not to flash?

- Natural lighting
- Low signal-to-noise ratio (SNR)
- Loss of details
- Longer exposure – motion blur

- Harsh, unnatural lighting
- High SNR
- More details
- May cause unwanted artifacts (red eye, shadows, specularities)
Why not both?

• The idea: use the good features of each photo to create a better image
Improvement: Joint Bilateral Filter

- In the flash image there are much more details.
- Why not use F to find edges?

\[
A_{p}(col) = \frac{1}{k(p(col))} \left( |p| - F_{p}(col) \right) A_{p'}(col)
\]

The difference
More details

• Denoising + detail transfer + masking shadows and specularities
More Examples
Dark Flash Photography
Krishnan, Fergus (SIGGRAPH 2009)

Dark flash is ~200 times dimmer than conventional
Computational Stereo
Computational Stereo

Left 2D image  Right 2D image  3D image
What is Disparity?

The amount to which a single pixel is displaced in the two images is called disparity. A pixel’s disparity is inversely proportional to its depth in the scene.
Disparity Encoding

The disparity of each pixel is encoded by a gray value. Light gray values represent high disparities, and dark gray values small disparities. The resulting image is called disparity map.
Disparity and Depth

The disparity map contains sufficient information for generating a 3D model
Stereo Correspondence
Stereo Rectification
Correspondence problem is hard

Data

Window-based matching

Ground-truth
Correspondence is hard

Y. Boykov, O. Veksler, and R. Zabih, Fast Approximate Energy Minimization via Graph Cuts, PAMI 2001
Active stereo with structured light

Project “structured” light patterns onto the object simplifies the correspondence problem
High Accuracy Stereo Depth Map using Structured Light
Scharstein, Szeliski (CVPR 2003)
High Accuracy Stereo Depth Map using Structured Light
Scharstein, Szeliski (CVPR 2003)
Discussion