PSFs and Bokeh

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Computational Photography

• About using cameras to capture data for computational processing, rather than making a pretty image on the sensor...

• Multispectral image processing
• New camera/sensor models
• Intelligent computer control of capture
• Detection/manipulation of image properties
Spring 2009, EE499

- Jennifer Danhauer, Joe Lanford, Ross Levine
- Project to capture a depthmap inside a Canon PowerShot using depth-from-focus
- CHDK scripting used so single press captures a sequence with different focus distances
- CHDK processing modified with custom C code to measure blur & combine images
- Blur measurement was fairly state-of-the-art
Measuring Focus Blur

- This is how contrast-detect autofocus works
- Various algorithms in the literature for determining local contrast between pixels...
  Sobel worked best
- Actually done on raw sensor data using just the green pixel values (they have less noise)
- Limited memory in camera... some cleverness to avoid keeping N images in memory
How Good Is The Depthmap?

- Accurate depths at edges
- No depth in featureless fields
- **Wrong depths near edges!**
  - Wrong by a lot
  - Wrong both directions
  - Seems to “echo” edges
What Went Wrong?

- What does an out-of-focus (OOF) point light source - point spread function (PSF) – look like?
What Went Wrong?

• Most image processing algorithms treat OOF point light sources as **Gaussian blur**:
They Look Like This

- Note the sharp edge!
Point Spread Function (PSF)

- Describes the response of an imaging system to a point source (impulse response)
- The spatial domain representation of the Modulation Transfer Function (MTF)
- An image is essentially the sum of the PSFs of all points of light in the scene
- PSF size grows in proportion to how OOF
The Wrong PSF Model!

But an OOF point light source imaged by a real lens (Takumar 135mm f/2.5) looks like:
Each Lens PSF Is Unique

- For a Minolta 50mm f/1.7 with barely visible fungus it looks like this:
Optical Formula Affects PSF

- For my Sony 18-70mm zoom at 18mm f/3.5 the PSF looks like this:
A Simple Retrofocus Lens PSF

- For my Vivitar 28mm f/2.5 it looks like this:
A Classic Mirror Lens PSF

- For my Bower 500mm f/6.3 mirror lens the PSF looks like this:
PSF with Spherical Aberration

Over

Under

Near

Far
Axial Chromatic Aberrations
Cat's Eye / Swirl Vignetting
Symmetric Near & Far

- Before and after focus are inverses (no, they are not ambiguous!)
- Funny things happen around focus
  - Different colors in focus at different depths
  - Partial “inversion” of pattern
Computational Photography Using PSF Structures

- After characterizing 100+ real lenses...
- Depth-from-focus/defocus, refocus/all-in-focus
- Diagnose lens defects like contamination and fabrication flaws (e.g., decentering)
- Forensically identify the type of lens
- Forensically identify the specific lens
- PSF substitution
- Structured apertures & apodization
Bokeh

- Japanese-derived word for the general properties of OOF regions
- Good bokeh come from Gaussian blur PSFs
- Nisen bokeh – double line artifacts
Minolta's STF (Smooth Trans Focus)

- The Sony/Minolta 135mm f/2.8 t/4.5 STF incorporates an apodizing element
Minolta's Maxixum 7 STF Mode

- Fakes apodization using multiple exposures!
- Here's my version using CHDK:

Bokeh Apodization Test, Aug 14, 2009

(bokeh apodization by dynamic variation of aperture)

Native PSF at F4  Gaussian PSF by invention  Manually set PSF by invention
PSF Substitution

- Commonly attempted for image refocus
- Can improve image Bokeh by replacing native PSF with a Gaussian blur (or other) PSF
- Can directly synthesize “3D” stereo pairs and enhance their apparent depth – more on that next lecture!