Digital Photography

Visual Imaging in the Electronic Age
Lecture #10
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Focus Fundamentals

Accommodation for a near target

Accommodation for a far target
Visual Acuity

• Visual acuity is defined as “1/a where a is the response in arc-minutes”.
• This acuity is usually measured by a grating test pattern and thus is defined using a line pair.
• It takes two pixels to generate a line pair (black and white).
• Based on a large number of tests, the resolution of the human eye is approximately 0.3 arc minutes.
Resolution Limits

\[ a = \text{distance from the screen} \]

\[ \theta = \text{angle measured in arc-minutes} \]
The triangle subtended by a 30 second angle

Sine of 30 sec = sine of 1/120 deg

= sin (0.0083333333)

= 0.000145444

Thus 18" sin(30 sec)

= 0.002617994"
End of Review
Moore’s Law

“Chip density doubles every 18 months.”

Processing Power \((P)\) in 15 years:

\[
P = P_{today} \left(2\right)^{\frac{15\ years}{18\ months}} = P_t \left(2\right)^{1.5} \\
= P_t \left(2\right)^{10} = 1000P_t
\]
History of Photography

Ancient — Camera Obscura – through pinhole

16\textsuperscript{th} - 17\textsuperscript{th} Century — Camera Obscura – improvements by enlarging hole and using telescopic lenses

1837 — Louis Daguerre – creates images on silverplated copper plates

1839 — Alexander Wolcott – added concave mirrors to increase light and was one of America’s first daguerrotype photographers

1861-65 — James Clerk-Maxwell – demonstrates color photography using RGB filters & 3 projectors
Pinhole Camera

Note that the entire image through the pinhole is totally in focus on a single image plane.
Camera Obscura

http://en.wikipedia.org/wiki/Camera_obscura
Daguerre’s Early Photograph 1838
Wolcott’s Camera

1859

Civil War - Mathew Brady 1860’s
Image Paradigm Shift 1855-1872

- To move from black and white imagery to color pictures. James Clerk Maxwell showed that by using red, green, and blue projectors he could generate color images.
- A change from single lenses to multiple lenses.
Maxwell’s Color Projection 1855-1872
1860 — Mathew Brady – covers American Civil War, first photojournalism

1877 — Eadweard Muybridge – “Do a horse’s four hooves ever leave the ground at once?” Using time-sequenced photographs of Leland Stanford’s horses to settle a bet among rich San Franciscans

1880 — George Eastman – sets up Eastman Dry Plate Company in Rochester, NY

1934 — Mannes & Godowsky – developed full color Kodachrome film
Color Film Paradigm Shift

From multiple lenses or multiple exposures to multiple layered film

The transition from the optical approach to the chemical approach formed the new basis for color photography

Mannes & Godowsky
1920’s
Protective Layer

Blue-sensitive Emulsion
Yellow Filter
Green-sensitive Emulsion
Interlayer
Red-sensitive emulsion
Foundation Layer
Acetate Base
Anti-halation Backing

(fig. 1.6, Color Photography, Robert Hirsch, p. 5)
Kodak’s Early Camera 1888

from The Story of Kodak, Douglas Collins 1990, p. 57
| Capturing Motion | Strobe Photography |
Eadweard Muybridge - Galloping Horse 1878
Newton’s Apple

Edgerton 1970

A low speed, ISO 32 film produces this fine grained image. The right image is a small portion of the whole negative on the left.

A high speed, ISO 400 film produces a coarser grain with less apparent sharpness in the image.
Polaroid Land Camera
Kodak color 35mm Film
CAN GEORGE FISHER FIX KODAK?
SHOOTOUT!

LEW PLATT, CEO, Hewlett-Packard

HOW HP PLANS TO TAKE ON KODAK—AND REVOLUTIONIZE THE WAY YOU CAPTURE AND PRINT IMAGES

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Digital Cameras
CCD Technology

• 1969  George Smith & Willard Boyle invented the CCD image sensor at Bell Labs. The Nobel Laureates were looking to develop a video phone.

• 1970  They built the world’s first solid state video camera

• 1981  Sony produced the Mavica, the first digital camera

• 1991  Kodak scientist creates the first professional digital camera with a 1.3 Megapixel sensor
How CCD’s Work

Photons incident on the silicon surface generate a charge that can be read by electronics.
CCD Technology

Fig. 2. Simple photodetector
Fig. 4. Typical scientific-grade CCD imager
1. After exposure to light, an electronic image accumulates as a pattern of charge in the parallel register.

2. Charge is shifted up the parallel register one row. The first row is shifted into the serial register.

3. The first pixel is serially shifted into the output node.

4. The charge at the output node is collected for signal processing.

5. The charge from the next pixel is shifted to the output node.

6. The charge at the output node is collected for signal processing.

7. After all pixels in the serial register are processed, the next row is shifted into the serial register.
Kodak DCS420 (Charge-Coupled Device)

$14,000 - June 1994
Bayer pattern

Cost of CMOS image sensors ~ $1
Foveon

- Founded by Dr. Carver Mead (1997)
- Uses CMOS technology (not CCD)

- Specifications and Performance
  - Resolution 16.8 Mpixels
  - 7 active transistors behind each pixel
  - Less interference, better focusing
  - More precise exposure times
  - Smarter pixels
Foveon Camera 16.8 Megapixels
New Chip Technology

Richard Merrill, Foveon’s senior scientist, beside a print of a cowboy taken using the company’s new chip technology

The fine detail of an eyebrow, above, showing hairs without breaking up into dots, or pixels.

FIG. 6
Foveon

Silicon color absorption

- Full spectrum
- Blue absorption
- Green absorption
- Red absorption

Foveon X3 sensor stack

- Blue sensor
- Green sensor
- Red sensor

Silicon wafer

 peny stack

≈ 7 microns

≈ 5 microns
Film, Digital, and Foveon Comparison

First came film.
COLOR FILM contains three layers of emulsion which directly record red, green, and blue light.

Then came digital.
TYPICAL DIGITAL SENSORS have just one layer of pixels and capture only part of the color.

Now there’s Foveon X3.
FOVEON X3 direct image sensors have three layers of pixels which directly capture all of the color.
Kodak DCS 460

- 1995 – the highest resolution digital camera ($35,600)
- 2000 – price had dropped to $2,500
CMOS Sensors
Requirements For Pervasive Digital Photography

• High resolution, low cost image acquisition devices

• Sufficient computer processing power and memory systems for digital manipulation

• Image enhancement software with easy-to-use interfaces

• High density, low-cost local storage systems
Requirements For Pervasive Digital Photography

- Cheap LCD displays for previewing

- Bandwidth! Bandwidth! Bandwidth!
  - High network bandwidth (wired) for distant transmission
  - Fast throughput (e.g. Firewire) for local transmission
  - Wireless bandwidth (local) for ease of use

- High quality, low cost digital printers
CONSUMER Digital Cameras 2012

Sony CyberShot
20 MegaPixels
$80

Kodak EASYSHARE Touch M5370
Cost: $129.95
16 Megapixels
PROFESSIONAL Digital Cameras

2014

Canon EOS 5DSR
50.6 MegaPixels
$3,899

Nikon Digital SLR
16.2 MegaPixels
$5,999
iPhone 6S Camera – 12 Mpxixels 2014
Nokia Lumia 1020 – 41 MPixels
• Can read letters on an airplane 11 miles away!
• 418,000 pixels/1 sq. mm (ball point pen)
Fly’s Eye
AWARE-2

http://mosaic dsp.duke.edu:90/aware/image_list/image_list/public
Eye of a Fly

AWARE-2 Duke University

http://www.nanowerk.com/spotlight/spotid=3744.php
AWARE-2

Samsung Galaxy S3

Aware2 Camera

http://www.kickstarter.com/projects/aqueti/carolina-zoomin
Creating Full View Panoramic Image Mosaics and Environment Maps

3D rotation registration of four images taken with a hand-held camera

Photo Stitching Panoramas
Photo Stitching Panoramas

• Registration
  – Matching features

• Calibration
  – Exposure
  – Lens corrections

• Blending
• GigaPan: Corcovado 67GP (first stitch)
End
Chromatic Aberration

Perfect Lens with no Chromatic Aberration

Longitudinal / Axial Chromatic Aberration

Legend
- Light Rays
- Optical Axis
- Best Focus Point

Legend
- RGB Color Rays
- Optical Axis
- Best Focus Point
Insect-Eye Camera MAVs

http://spectrum.ieee.org/robotics/robotics-hardware/insecteye-camera-offers-wideangle-vision-for-tiny-drones