Color Digital Imaging: Cameras, Scanners and Monitors

H. J. Trussell
Dept. of Electrical and Computer Engineering
North Carolina State University
Raleigh, NC 27695-7911
hjt@ncsu.edu

Color Imaging Devices
- Digital still camera
- Document scanners
- Flat panel displays
- Digital projectors
- Desktop printers
- Commercial printers
Spectral Images

RGB = (0.7082 0.6152 0.5722)  RGB = (0.6944 0.6097 0.5620)

Colorimetry
Three types of cones

Red, Green, Blue
Really
Long, Medium, Short wavelengths
Colorimetry

Three CIE XYZ Color Matching Functions

![CIE XYZ color matching functions graph]

Colorimetry: Obtaining CIE XYZ values

XYZ = (5.59, 4.55, 1.29)
Colorimetry for Cameras and Scanners

Sensor Filters - they are not equivalent to either the human eye or the CIE XYZ color matching functions

Results of summation of product must be transformed by mathematical estimation method to approximate CIE values

Digital Still Camera – Pipeline

1. Exposure adjustment
2. Optics/focus
3. Initial image capture/digitization
4. Dark noise removal
5. Uniformity adjustments
6. Demosaicking
7. White balance
8. Appearance adjustments
9. Compression/file formatting
Digital Still Camera
Mosaic and Demosaic

<table>
<thead>
<tr>
<th>Combined</th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Combined Image" /></td>
<td><img src="image2.png" alt="Red Image" /></td>
<td><img src="image3.png" alt="Green Image" /></td>
<td><img src="image4.png" alt="Blue Image" /></td>
</tr>
</tbody>
</table>

Original: ![Original Image](image5.png)
Demosaicked: ![Demosaicked Image](image6.png)

Demosaicking – Bilinear Interpolation

Original- high resolution: ![Original Image](image7.png)
Bilinear interpolation of mosaicked data: ![Interpolated Image](image8.png)
**Demosaicking Approaches**

*Use correlation between bands but avoid interpolation across edge boundaries*

*Estimate edge gradients first then use these to weight interpolation of adjacent bands. May use appearance related properties to determine the color space in which to interpolate.*

*Use of local/global statistical characterization to enforce constraints or properties*

*Comparison of several demosaicking methods – Courtesy of Bas, Gun, Altunbasak, Mersereau, Shafer*
Input Device Design
Adjusting for illumination

Can make corrections if P is large and represents continuous spectrum. For 3-band cameras estimation is required.

White Balance
Compensate for illumination

From left to right, tungsten illumination with fluorescent white balance, tungsten white balance with flash illumination, tungsten illumination with tungsten white balance, tungsten illumination with daylight white balance.
Resolution Problems (Sampling – Moire effects)

Problems caused by saturation of sensors
**Image Scanner**

*Scanner – configuration #1*

**CCD Scanner**

Differences from Camera:
Controlled illumination, controlled geometry, no demosaicking

---

**Output Devices**

- CRT monitors (old technology)
- Flat Panel Displays
- Digital Projectors
- Photographic Film/Paper
- Commercial Printing
- Desktop Printing
  - Inkjet
  - Electrophotographic
  - Dye Sublimation
Flat Panel Displays
Technology

(a)
(b)

Fluorescent (Backlight)
Rear polarizer
Rear glass with TFT array and row/column drivers
Liquid crystal layer
Front glass with color filters
Front polarizer

Colored lighting (e.g. LEDs)
Green
Blue
Red
Diffuser
Rear polarizer
Rear glass with TFT array and row/column drivers
Liquid crystal layer
Front polarizer

Colorimetry
Mathematics of Color – Color Matching Set-up
Colorimetry

Mathematics of Color: Color Matching Functions

Primaries are monochrome at
435.8nm
546.1nm
700nm

Negative values indicate gamut problem for a single set of primaries

Flat Panel Display

Flat Panel Displays: Backlighting and Filters

Major problem is obtaining uniform illumination –
  fluorescent tubes
  LEDs
  Electroluminescent

Color Gamut: defined by filters and illuminant

Multiple colors of LEDs can extend gamut
combine with filters can produce more saturated color

Patent 7800822 HDR displays with individually-controllable color backlights (2010)
**Flat Panel Displays**

backlighting examples

- fluorescent
- electroluminescent
- LED

**Magnification of Flat Panel Screen**

New displays can address individual red, green and blue parts of pixel (subpixel imaging)
**Digital Projectors**

Digital Light Processors (DLP) shown here
Liquid Crystal Displays (LCD)

DMD is digital micromirror device

**Micromirror Devices**

Schematic
The time the mirror is pointed toward the lens determines the brightness of the pixel.

Actual device

Electron micrograph with fly’s leg
Light Path in DLP Projector

Color Wheel spins at about 14,400RPM or 4 revolutions per frame (30 frames/sec)

Color Device Gamut

Gamut: the range of colors that a device can produce
Device gamuts (range) are 3-D

Gamut – defined as
\[ \Omega_{gamut} = \{ \mathbf{t} \in \Omega_{DICS} \mid \text{there is a } \mathbf{c} \in \Omega_{DD} \text{ where } \mathcal{F}_{device}(\mathbf{c}) = \mathbf{t} \} \]

CIE L*A*B* Gamuts
Monitor (grid) vs. Printer (solid) Gamut
Could represent flat panel display and DLP projector.
Gamut Mapping Problems - projection to boundary

Points very distinct in region B are mapped to the same point

Point close to point A get mapped to very different colors

Solutions use color appearance effects, mapping to points inside gamut, etc.
Characterization of Devices

Characterization: Gamut Mapping – Example 12.4 Monitor gamut to printer

(a) Test colors generated from monitor values. See text for details of sampling.

Gamut mapping using profile of dye-sub printer and closest in-gamut point, along constant hue angle (preserving lightness)
Note blocking artifacts where boundaries meet.
Characterization of Devices

Characterization: Gamut Mapping – Example 12.4 Monitor gamut to printer

Gamut mapping using profile of dye-sub printer and closest in-gamut point, along constant hue angle (preserving lightness) – out-of-gamut points mapped to black
Note: lack of sharp boundaries due to display averaging.

---

Color in Digital Imaging

Lots of neat devices and theory
that interface with the worlds of science, engineering, design, entertainment

To be continued
Color in Digital Imaging

Lots of neat problems
Waiting for neat solutions

An Example Problem
accurate reproduction

\[ H(\cdot) = F^{-1}_{\text{display}} \left( F^{-1}_{\text{record}}(\cdot) \right) \]