TDI2131 Digital Image Processing

Color Image Processing
Lecture 10

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Some portions of content adapted from Zhu Liu, AT&T Labs. Most figures from Gonzalez/Woods.
Some Announcements

• **Assignment 3** is out.
  – Submission deadline: **11.59PM, 28 April 2010 (Wed, Week 14)**. No further extensions possible!
  – Presentation – **29 April 2010, 4-6pm (Thurs, Week 14)**

• You are to work in groups of 1-2 people (max. 2)

• **Term Test, Week 12** – **12 April 2010 (Mon), 8pm, FIT CR2003 (usual lecture room)**
Lecture Outline

• Color Perception

• Color Representation
  – Trichromatic Color Mixing Theory
  – Color Models
  – Conversions between Color Models

• Pseudocolor Image Processing
  – Intensity Slicing
Light is part of the EM Wave
Illuminating & Reflecting Sources

- Colors that humans or some animals perceive in an object – determined by nature of the light reflected from the object.
- A “body” that reflects light balanced in all visible wavelengths appears WHITE to the observer.
- A “body” that favors reflectance in a limited range of the visible spectrum shows some shades of color.
Illuminating & Reflecting Sources

• **Illuminating Sources** (primary light)
  – Emit light (e.g. the sun, light bulb, TV monitors)
  – Perceived color depends on emitted frequency
  – Follow additive rule – R+G+B = White

• **Reflecting Sources** (secondary light)
  – Reflect an incoming light (e.g. the color dye, matte surface, cloth)
  – Perceived color depends on reflected material
  – Follow subtractive rule – R+G+B = Black
Characterization of Light

• Central to the “science of color”

• If the light is **achromatic** (void of color), its only attribute is its **intensity**, or amount – monochrome, grayscale

• Chromatic light spans the EM spectrum from 400–700nm. It has 3 basic quantities:
  
  – **Radiance** – amount of energy from source
  – **Luminance** – amount of energy perceived by observer
  – **Brightness** – a subjective descriptor, not possible to measure, describes color sensation
Tri-chromatic Color Mixing

- Tri-chromatic color mixing theory
  - Any color can be obtained by mixing three primary colors with a right proportion

- Primary colors for illuminating sources
  - Red, Green Blue (RGB)
  - Color monitor works by mixing red, green and blue intensities – CRT monitors use separate color guns, LCD mixes three subpixels to generate a single color pixel.

- Primary colors for reflecting sources
  - Cyan, Magenta, Yellow (CMY)
  - Color printer works by using cyan, magenta, yellow and black dyes (CMYK)
RGB vs CMY

Magenta = Red + Blue
Cyan = Blue + Green
Yellow = Green + Red

Magenta = White - Green
Cyan = White - Red
Yellow = White - Blue
Color Image Composition

Red
Green
Blue
Attributes of Color

- To represent/describe color in an intuitive way, using properties easy for human interpretation, use the attributes of **brightness** (luminance), **hue** and **saturation** (both represent chromaticity)

- Represented by a “color cone” or “color solid”

- These attributes are used in the HSI/HSV color model
Tristimulus Values

• Tristimulus Value
  – The amounts of red, green and blue needed to form any particular color are called the tristimulus values, denoted by X, Y and Z.
  – Trichromatic coefficients:

\[
x = \frac{X}{X + Y + Z}, \quad y = \frac{Y}{X + Y + Z}, \quad z = \frac{Z}{X + Y + Z}.
\]

\[x + y + z = 1\]

– Only two chromaticity coefficients are necessary to specify the chrominance of a light
CIE Chromaticity Diagram

- **CIE** (Commission Internationale de L'Eclairage, International Commission on Illumination) system of color specification
  - X axis: red, Y axis: green
  - e.g. GREEN: x: 25%, y: 62%, z:13%
  - Colors on the boundary = spectrum colors at highest saturation
Color Gamut

- Each color model has different color range (or gamut). RGB model has larger gamut than CMY.
- Thus, some color that appears on a screen may not be printable and is replaced by the closest color in the CMY gamut.
- A line segment indicates all colors that can be produced by mixing two colors corresponding to the endpoints of the line.
Color Models

• **Color Specification** – 3 primary or secondary colors
  - Red, Green, Blue
  - Cyan, Magenta, Yellow

• **Luminance and Chrominance Specification**
  - HSB or HSI (Hue, Saturation, and Brightness or Intensity)
  - YIQ (used in NTSC color TV)
  - YCbCr (used in digital color TV)

• **Amplitude Specification**
  - 8 bits per color component, or 24 bits per pixel
  - Total of 16 million colors
  - A 1k x 1k true RGB color requires 3 MB memory
RGB Color Model

RGB 24-bit color cube
CMY and CMYK Color Models

- High-end display cards/monitors provide rendition of colors in a 24-bit RGB true color image, BUT some applications/systems are limited

- Sometimes, it makes no sense to use more than a few hundred colors...

- Given the variety of systems in use today, it is of interest to have a subset of colors that are likely to be reproduced faithfully, reasonably independent of viewer hardware capabilities – safe RGB colors or all-systems-safe colors

- In Internet applications, they are called safe Web colors or safe browser colors.
CMY and CMYK Color Models

- There are 216 safe RGB colors

FIGURE 6.10
(a) The 216 safe RGB colors.
(b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

FIGURE 6.11 The RGB safe-color cube.
CMY and CMYK Color Models

- Conversion between RGB and CMY (assuming max value is 1)

\[
\begin{bmatrix}
C \\
M \\
Y
\end{bmatrix} = \begin{bmatrix}
1 \\
1 \\
1
\end{bmatrix} - \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}, \quad \begin{bmatrix}
R \\
G \\
B
\end{bmatrix} = \begin{bmatrix}
1 \\
1 \\
1
\end{bmatrix} - \begin{bmatrix}
C \\
M \\
Y
\end{bmatrix}.
\]

- Equal amounts of Cyan, Magenta, and Yellow produce black. In practice, this produce a muddy-looking black. To produce true black, a fourth color, black is added, which is specified in CMYK color model as “K”. The CMYK model is commonly used by printers and publishers.
HSI Color Model

- **Hue**: Dominant colors as perceived by an observer. It is an attribute associated with the dominant wavelength

- **Saturation**: Relative purity or amount of white light mixed with a hue. The pure spectrum colors are fully saturated. e.g. pink and lavender are less saturated

- **Intensity**: Reflects the brightness of the color
HSI Color Model

- **Hue**: Dominant colors as perceived by an observer. It is an attribute associated with the dominant wavelength.

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HSI Color Model -- Illustrations

HSI model is based on triangular and circular color planes
Conversions between RGB and HSI

• Converting color from RGB to HSI

\[
H = \begin{cases} 
\theta & \text{if } B \leq G \\
360 - \theta & \text{if } B > G 
\end{cases} \quad \text{with} \quad \theta = \cos^{-1}\left( \frac{1}{2} \left[ \frac{(R-G)+(R-B)}{[ (R-G)^2 + (R-B)(G-B) ]^{1/2}} \right] \right)
\]

\[
S = 1 - \frac{3}{(R+G+B)} \min(R, G, B)
\]

\[
I = \frac{1}{3} [R + G + B]
\]

• Converting color from HSI to RGB

**RG sector (0 \leq H < 120)**

\[
B = I (1 - S)
\]

\[
R = I \left(1 + \frac{S \cos H}{\cos(60-H)}\right)
\]

\[
G = 1 - (R + B)
\]

**GB sector (120 \leq H < 240)**

\[
R = I (1 - S)
\]

\[
G = I \left[1 + \frac{S \cos(H - 120)}{\cos(60 - (H - 120))}\right]
\]

\[
B = 1 - (R + G)
\]

**BR sector (240 \leq H < 360)**

\[
G = I (1 - S)
\]

\[
B = I \left[1 + \frac{S \cos(H - 240)}{\cos(60 - (H - 240))}\right]
\]

\[
R = 1 - (G + B)
\]
Comparison of Different Color Spaces
YIQ Color Coordinate System

- YIQ is defined by the National Television System Committee (NTSC)
  - Y describes the luminance, I and Q describes the chrominance
  - A more compact representation of the color
  - YUV plays similar role in PAL and SECAM

- Conversion between RGB and YIQ

\[
\begin{bmatrix}
Y \\
I \\
Q
\end{bmatrix} = \begin{bmatrix}
0.299 & 0.587 & 0.114 \\
0.596 & -0.274 & -0.322 \\
0.211 & -0.523 & 0.311
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}, \quad \begin{bmatrix}
R \\
G \\
B
\end{bmatrix} = \begin{bmatrix}
1.0 & 0.956 & 0.621 \\
1.0 & -0.272 & -0.649 \\
1.0 & -1.106 & 1.703
\end{bmatrix} \begin{bmatrix}
Y \\
I \\
Q
\end{bmatrix}
\]
YUV/YCbCr Coordinate System

- YUV is the color coordinate used in color TV in PAL system, somewhat different from YIQ
- YCbCr is the digital equivalent of YUV, used for digital TV, with 8 bits for each component, in range of 0-255.

\[
\begin{bmatrix}
Y \\
C_b \\
C_r
\end{bmatrix} =
\begin{bmatrix}
0.257 & 0.504 & 0.098 \\
-0.148 & -0.291 & 0.439 \\
0.439 & -0.368 & -0.071
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix} +
\begin{bmatrix}
16 \\
128 \\
128
\end{bmatrix}
\]

\[
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix} =
\begin{bmatrix}
1.164 & 0.000 & 1.596 \\
1.164 & -0.392 & -0.813 \\
1.164 & 2.017 & 0.000
\end{bmatrix}
\begin{bmatrix}
Y - 16 \\
C_b - 128 \\
C_r - 128
\end{bmatrix}
\]
Criteria of Choosing Color Coordinates

• The type of representation depends on the applications at hand
  – For display or printing, choose primary colors so that more colors can be produced. E.g. RGB for displaying and CMY for printing
  – For analytical analysis of color differences, HSI is more suitable
  – For transmission or storage, choose a less redundant representation, e.g. YIQ or YUV or YCbCr
A Past Year FYP...

- “RGB-H-CbCr Skin Colour Model for Human Face Detection”, Nusirwan Anwar & Kit Chong Wei, FYP 2006
  - Developed a new color-based technique (RGB-H-CbCr) of segmenting skin regions for face detection
  - Research paper published at M2USIC'06 conference in KL
And this year...

- Your turn to give it a try – **Assignment 3 on Automatic Color-based Face Detection**
- How does automatic face detection work using image processing?
Pseudocolor Image Processing

- **Intensity Slicing**: Display different gray levels as different colors
  - Can be useful to visualize medical/scientific/vegetation imagery
    - E.g. If one is interested in features with a certain intensity range of several intensity images

- **Frequency slicing**: Decomposing an image into different frequency components and represent them using different colors.
Intensity Slicing

Pixels with gray-scale (intensity) value in the range of \((f_{i-1}, f_i)\) are rendered with color \(C_i\)
Example: Intensity Slicing

**FIGURE 6.20** (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)

**FIGURE 6.22** (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South American region. (Courtesy of NASA.)
Recommended Readings

- Digital Image Processing (3rd Edition), Gonzalez & Woods,
  - Chapter 6: Color Image Processing
    - 6.1-6.5 (Week 10)