Lecture 12 Color model and color image processing

- Color fundamentals
- Color models
- Pseudo color image
- Full color image processing
Color fundamental

• The color that humans perceived in an object are determined by the nature of the light reflected from the object.

• Light is electromagnetic spectrum.

**FIGURE 6.2** Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)
Visible light and Color

- Visible light is composed of a relatively narrow band of frequencies in the ES.
- Human color perceive is a composition of different wavelength spectrum
- The color of an object is a body that favours reflectance in a limited range of visible spectrum exhibits some shade of colors
- Example
  - White: a body that reflects light that balanced in all visible wavelengths
  - E.g. green objects reflect light with wavelength primarily in the 500 to 570 nm range while absorbing most of the energy at other wavelengths.
Characterization of light

• If the light achromatic (void of color), if its only attribute is intensity. Gray level refers to a scalar measure of intensity that ranges from black, to grays, and finally to white

• Chromatic light spans the ES from about 400 to 700 nm

• Three basic quantities are used to describe the quality of a chromatic light source

• Radiance: total amount of energy flows from the light source

• Luminance: amount of energy perceive from light source

• Brightness: a subjective descriptor that is practically impossible to measure
Color sensors of eyes: cones

- Cones can be divided into three principle sensing categories, roughly red (65%), green (33 %), blue (2%).
- Colors are seen as variable combination of the so-called primary colors Red (R), Green (G), and blue (B).

**FIGURE 6.3**
Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.
Primary colors and secondary colors

• CIE (Commission Internationale de l’Eclariage) standard for primary color
  – Red: 700 nm
  – Green: 546.1 nm
  – Blue: 435.8 nm

• Primary color can be added to produce secondary colors
  – Primary colors can not produce all colors

• Pigments (colorants)
  – Define the primary colors to be the absorbing one and reflect other two
Characterization

- Brightness, hue, and saturation
- Brightness: achromatic notion of intensity
- Hue: attribute associated with dominating wavelength in a mixture of light waves, i.e., the dominant color perceived by observer
- Saturation: refers to the relative purity or the amount white light mixed with a hue.
- Hue and saturation together are called chromaticity, so a color can be characterized by its brightness and chromaticity
- The amount of red, green and blue to form a particular color are called tristimulus values, denoted by X, Y, Z. The a color is defined by

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

\[x + y + z = 1\]
**FIGURE 6.5**
Chromaticity diagram.
(Courtesy of the General Electric Co., Lamp Business Division.)

**FIGURE 6.6**
Typical color gamut of color monitors (triangle) and color printing devices (irregular region).
Color models (color space, or color system)

• A color model is a specification of a coordinate system and subspace where each color is represented as a single point.

• Examples
  – RGB
  – CMY (cyan, magenta, yellow)/CMYK (cyan, magenta, yellow, black)
  – NTSC
  – YCbCr
  – HSV
  – HSI
RGB Color models

- (R, G, B): all values of R, G, B are between 0 and 1.
- With digital representation, for a fixed length of bits each color element. The total number of bits is called color depth, or pixel depth. For example, 24-bit RGB color (r, g, b), 8-bits for each color. The 8-bit binary number $r$ represents the value of $r/256$ in $[0,1]$.
Displaying Colors in RGB model

**FIGURE 6.9**
(a) Generating the RGB image of the cross-sectional color plane \((127, G, B)\).
(b) The three hidden surface planes in the color cube of Fig. 6.8.
<table>
<thead>
<tr>
<th>Number System</th>
<th>Color Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hex</td>
<td>00</td>
</tr>
<tr>
<td>Decimal</td>
<td>0</td>
</tr>
</tbody>
</table>

**TABLE 6.1**
Valid values of each RGB component in a safe color.

**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).
CMY and CMYK model

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

- CMYK: (C, M, Y, B), where B is a fixed black color. This basically for printing purpose, where black is usually the dominating color. When printing black, using B rather than using (C, M, B) = (1, 1, 1)
NTSC color space, YCbcCr, HSV

- **NSTC (YIQ):** Y-luminance, I-hue, Q-Saturation

\[
\begin{bmatrix}
Y \\
I \\
Q
\end{bmatrix} =
\begin{bmatrix}
0.299 & 0.587 & 0.114 \\
0.596 & -0.274 & -0.322 \\
0.211 & -0.523 & 0.312
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]

- **YCbcCr color space**

\[
\begin{bmatrix}
Y \\
Cb \\
Cr
\end{bmatrix} =
\begin{bmatrix}
16 \\
128 \\
128
\end{bmatrix} +
\begin{bmatrix}
65.481 & 128.553 & 24.966 \\
037.797 & -74.203 & 112 \\
112 & -93.786 & -18.214
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]
HSI

- HSI color space: H – hue, S-saturation, I-intensity

\[
H = \begin{cases} 
\theta, & B \leq G \\
360 - \theta, & B > G 
\end{cases}
\]

\[
\theta = \cos^{-1} \left\{ \frac{1}{2} \left[ \frac{(R - G) + (R - B)}{[(R - G)^2 + (R - B)(G - B)]^{1/2}} \right] \right\}
\]

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

\[
I = \frac{1}{3} (R + G + B)
\]
Pseudocolor image processing

- Pseudocolor image processing is to assign colors to gray values based on a specified criterion.
- Purpose: human visualization, and interpretation for gray-scale events
- Intensity slicing: partition the gray-scale into P+1 intervals, $V_1, V_2, \ldots, V_{p+1}$. Let $f(x, y) = c_k$, if $f(x, y)$ is in $V_k$ where $c_k$ is the color assigned to level $k$.

**Figure 6.18** Geometric interpretation of the intensity-slicing technique.

**Figure 6.19** An alternative representation of the intensity-slicing technique.
**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 6.21
(a) Monochrome X-ray image of a weld. (b) Result of color coding.
(Original image courtesy of X-TEK Systems, Ltd.)
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.)
Intensity to color transformation

- Transform intensity function \( f(x,y) \) into three color components.

![Diagram showing the process of intensity to color transformation](image)

**FIGURE 6.23** Functional block diagram for pseudocolor image processing. \( f_R, f_G, \) and \( f_B \) are fed into the corresponding red, green, and blue inputs of an RGB color monitor.
FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.
Multiple images

- If there are multiple image of the same sense available, additional processing can be applied to make one image.

![Diagram showing transformations and additional processing](image-url)

**Figure 6.26** A pseudocolor coding approach used when several monochrome images are available.
FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral images courtesy of NASA.)
FIGURE 6.28
(a) Pseudocolor rendition of Jupiter Moon Io.
(b) A close-up.
(Courtesy of NASA.)
Basics of full-color image processing

• Full-color image

\[
c(x, y) = \begin{bmatrix} c_R(x, y) \\ c_G(x, y) \\ c_B(x, y) \end{bmatrix} = \begin{bmatrix} R(x, y) \\ G(x, y) \\ B(x, y) \end{bmatrix},
\]

\[
x = 0, 1, ..., M - 1, \quad y = 0, 1, ..., N - 1
\]

• Processing method can be applied to each color component.
  – Apply to both scalar and vector
  – Operation on each component is independent of the other component
\( x, y \)

**Spatial mask**

Gray-scale image

RGB color image

**FIGURE 6.29**

Spatial masks for gray-scale and RGB color images.
FIGURE 6.30  A full-color image and its various color-space components. (Interactive.)
Color transformation

• Transformation within a single color model

\[ g(x, y) = T[f(x, y)] \]
\[ s_i = T_i(r_1, r_2, \ldots, r_n), i = 1, \ldots, n \]

• Examples:

\[ g(x, y) = kf(x, y), 1 < k < 1 \]

\[ HSI : s_3 = kr_3 \]

\[ RGB : s_i = k_ir_i, i = 1, 2, 3 \]

\[ CMY(K) : s_i = kr_i + (1 - k), i = 1, 2, 3 \]
FIGURE 6.31
Adjusting the intensity of an image using color transformations.
(a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$).
(c)-(e) The required RGB, CMY, and HS1 transformation functions.
(Original image courtesy of McfData Interactive.)
**Figure 6.32**
Complements on the color circle.

**Figure 6.33**
Color complement transformations.
(a) Original image.
(b) Complement transformation functions.
(c) Complement of (a) based on the RGB mapping functions.
(d) An approximation of the RGB complement using HSI transformations.
Color slicing

• High light a specific range of colors in an image

\[
s_i = \begin{cases} 
0.5 & \left| r_j - a_j \right| > \frac{W}{2}, i = 1, 2, \ldots, n \\
 0.5 \sum_{j=1}^{n} (r_j - a_j)^2 > R_0^2, i = 1, 2, \ldots, n \\
 0.5 & \text{otherwise} \\
r_i & \text{otherwise}
\end{cases}
\]

**FIGURE 6.34** Color-slicing transformations that detect (a) reds within an RGB cube of width \( W = 0.2549 \) centered at \((0.6863, 0.1608, 0.1922)\), and (b) reds within an RGB sphere of radius 0.1765 centered at the same point. Pixels outside the cube and sphere were replaced by color \((0.5, 0.5, 0.5)\).
Tone and Color Corrections

\[ L^* = 116h\left(\frac{Y}{Y_W}\right) - 16 \]

\[ a^* = 500\left[h\left(\frac{X}{X_W}\right) - h\left(\frac{Y}{Y_W}\right)\right] \]

\[ b^* = 200\left[h\left(\frac{Y}{Y_W}\right) - h\left(\frac{Z}{X_W}\right)\right] \]

\[ h(q) = \begin{cases} 
 3\sqrt{q} - 0.5 & q > 0.008856 \\
 7.787q + 16/116 & q \leq 0.008856 
\end{cases} \]

**FIGURE 6.35** Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.
FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.
FIGURE 6.36 Color balancing corrections for CMYK color images.
Histogram Processing

**FIGURE 6.37**
Histogram equalization (followed by saturation adjustment) in the HSI color space.
Smoothing and Sharpening

• Color image smoothing.

\[
\bar{c}(x, y) = \frac{1}{K} \sum_{(s,t) \in S_{xy}} c(s, t) = \begin{bmatrix}
\frac{1}{K} \sum_{(s,t) \in S_{xy}} R(s, t) \\
\frac{1}{K} \sum_{(s,t) \in S_{xy}} G(s, t) \\
\frac{1}{K} \sum_{(s,t) \in S_{xy}} B(s, t)
\end{bmatrix}
\]
FIGURE 6.38
(a) RGB image.
(b) Red component image.
(c) Green component.
(d) Blue component.
FIGURE 6.39 HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.
• Color Image Sharpening

\[ cs(x, y) = c(x, y) - \bar{c}(x, y) \]

\[ \nabla^2[c(x, y)] = \begin{bmatrix} \nabla^2[R(x, y)] \\ \nabla^2[G(x, y)] \\ \nabla^2[B(x, y)] \end{bmatrix} \]

\[ cs(x, y) = c(x, y) - \nabla^2[c(x, y)] \]
Figure 6.40 Image smoothing with a $5 \times 5$ averaging mask. (a) Result of processing each RGB component image. (b) Result of processing the intensity component of the HSI image and converting to RGB. (c) Difference between the two results.
FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the HSI intensity component and converting to RGB. (c) Difference between the two results.
Color image noise

**FIGURE 6.48**
(a)–(c) Red, green, and blue component images corrupted by additive Gaussian noise of mean 0 and variance 800.
(d) Resulting RGB image. [Compare (d) with Fig. 6.46(a).]
**FIGURE 6.49** HSI components of the noisy color image in Fig. 6.48(d). (a) Hue. (b) Saturation. (c) Intensity.
FIGURE 6.50  (a) RGB image with green plane corrupted by salt-and-pepper noise.  (b) Hue component of HSI image.  (c) Saturation component.  (d) Intensity component.