Today’s Agenda

• Color image processing

• Review for Midterm
**Chromaticity**

**Tristimulus values of XYZ space**

\[
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix} = \begin{bmatrix}
0.49 & 0.31 & 0.20 \\
0.17697 & 0.81240 & 0.01063 \\
0.00 & 0.01 & 0.99
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]

**CIE XYZ matching function**

\[
X = \int_0^\infty I(\lambda) \bar{x}(\lambda) d\lambda
\]

\[
Y = \int_0^\infty I(\lambda) \bar{y}(\lambda) d\lambda
\]

\[
Z = \int_0^\infty I(\lambda) \bar{z}(\lambda) d\lambda
\]

**Luminance**

\[
x = \frac{X}{X + Y + Z}
\]

\[
y = \frac{Y}{X + Y + Z}
\]

\[
z = \frac{Z}{X + Y + Z}
\]

\[\Rightarrow z = 1 - x - y\]
Chromaticity Diagram

x and y to represent colors

Pure color and fully saturated
Equal energy with zero saturation
Mixed color with less saturation
Chromaticity Diagram (Cont’d)

**Color mixing:** any color on a line segment can be generated by the two ending points in the color diagram

**Metamerism:** the same color can be generated with different combinations of source colors with the same tristimulus values
Color Gamut

- **Color gamut:** a complete subset of colors can be displayed on a device or represented by a color space.

- The color represented by 3 given colors resides in the triangle formed by the 3 points.

- Not all colors can be represented by 3 primary colors.

**FIGURE 6.6** Typical color gamut of color monitors (triangle) and color printing devices (irregular region).
Color Models

**Color model (space/system):** a coordinate system or a subspace to represent the colors

- RGB model: monitors and cameras
- CMY (Cyan, magenta, and yellow): printing
- HSI (Hue, saturation, and intensity): separate color and gray level information
RGB Model

3D Cartesian coordinate system

All colors are normalized to [0, 1]

Pixel depth: number of bits to represent each pixel in the RGB space
RGB Model (Cont’d)

**FIGURE 6.8** RGB 24-bit color cube.
CMY/CMYK Model

CMY (Cyan, Magenta, Yellow)

- Represent the light reflected from the surface.

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

CMYK (CMY + Black)

MIXTURES OF PIGMENTS (Subtractive primaries)

PRIMARY AND SECONDARY COLORS OF LIGHT AND PIGMENT
HSI Model

A better model to describe colors.

- Hue: the dominant color observed
- Saturation: the purity of the color (how much the color is polluted by white color)
- Value/Intensity: intensity level
HSI Model

A better model to describe colors.
• Hue: the dominant color observed
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• Value/Intensity: intensity level
HSI Model

- H: Hue
- S: Saturation
- I: Intensity

- Cyan, Green, Yellow, Red, Blue, Magenta
- I = 0.75
- I = 0.5
HSI to RGB

Assume RGB values have been normalized to $[0,1]$

$$H = \begin{cases} 
\frac{\theta}{360} & \text{if } B \leq G \\
1 - \frac{\theta}{360} & \text{if } B > G 
\end{cases} \quad \text{where} \quad \theta = \cos^{-1} \left\{ \frac{0.5[(R-G)+(R-B)]}{\left[ (R-G)^2 + (R-B)(G-B) \right]^{1/2}} \right\}$$

$$S = 1 - \frac{3}{R+G+B} \min(R,G,B) \quad I = \frac{R+G+B}{3}$$

HSI values are in $[0,1]$
Case Study for RGB-HSI

Original RGB

Hue

Saturation

Intensity

0 1 0
0 0 1
0 0 0

0 1 0
0 0 1
1 0 1

0 1 0
1 0 1
1 0 1

0 1 0
1 0 1
1 0 1
**HSI to RGB**

**Recover H to [0 360]**

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

\[
B = I(1 - S) \quad R = I \left[ 1 + \frac{S \cos H}{\cos(60 - H)} \right] \quad G = 3I - (R + B)
\]

**GB sector** ($120 \leq H < 240$): \quad $H = H - 120$

\[
R = I(1 - S) \quad G = I \left[ 1 + \frac{S \cos H}{\cos(60 - H)} \right] \quad B = 3I - (R + G)
\]

**BR sector** ($240 \leq H \leq 360$): \quad $H = H - 240$

\[
G = I(1 - S) \quad B = I \left[ 1 + \frac{S \cos H}{\cos(60 - H)} \right] \quad R = 3I - (G + B)
\]
HSI Model

**FIGURE 6.15** HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.
Manipulate

Hue  Saturation  Intensity
**Full Color Image in Different Color Space**

**FIGURE 6.30** A full-color image and its various color-space components. (Interactive.)
Pseudo Color Image Processing

Pseudo color/false color: assign colors to gray values

Enhance the visualization quality of the image

• Segmentation results

• Enhance the intensity difference
Intensity Slicing

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

**Figure 6.19** An alternative representation of the intensity-slicing technique.
Pseudo Color Image Processing

Pseudo color/false color: assign colors to gray values

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Intensity Slicing

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

**FIGURE 6.19** An alternative representation of the intensity-slicing technique.
Examples of Intensity Slicing

**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 6.20** (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.)
Examples of Intensity Slicing

**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.)
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.
Example

**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.
Full-color Image Processing

Pixel in color image \( p(x, y) = \begin{bmatrix} p_r(x, y) \\ p_g(x, y) \\ p_b(x, y) \end{bmatrix} \)

- Process each component/channel individually, then generate the composite image
- Work on each pixel individually
Color Transformation

For a color image with n components

\[ s_i = T_i(r_1, r_2, \cdots, r_n), \quad i = 1, 2, \cdots, n \]

- Modify intensity
- Color complement (“negative” color image)
- Color slicing
- Tonal correction
- Color balancing
- Histogram processing
Examples of Color Image Transformation

Original image

Intensity modification

Complement color

Color slicing

HSI

RGB

RGB
Tonal Correction

Correct the tonal range (distribution of color intensities)

• Recall the intensity transformation in the gray level images

• For RGB model, each component has the same transformation function

• For HSI model, the transformation is applied on the intensity component only

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.
Color Balancing

Correct color unbalance by analyzing a known color in image
Histogram Processing

Step 1: Histogram equalization

Step 2: Saturation adjustment

FIGURE 6.37
Histogram equalization (followed by saturation adjustment) in the HSI color space.
Reading Assignment

• Reading Chapter 6.6, 6.7, 6.8
• Read Chapter 7 (Wavelets and Multiresolution Processing)
Review of Chapter 2- Chapter 5

Chapter 2
- Human vision system
- Basics of image processing

Chapter 3
- Intensity transformation
- Spatial filtering

Chapter 4
- Fourier transform
- Image convolution in frequency domain

Chapter 5
- Image denoise
- Image degradation
- Image restoration

Chapter 6
- Fundamentals of color image processing
- Color transformation
Human Vision System

- Geometrical relationship between the real object and the image of the object
- The minimum size of the object you can “see”

Brightness adaption
Basics of Image Processing

\[ f(x, y) = i(x, y) \cdot r(x, y) \]

- Image sampling and quantization
  - Spatial/intensity resolution
- Dynamic range of the image
  \[ \frac{I_{\text{max}}}{I_{\text{min}}} \]
- Image representation and storing
- Image interpolation
  - Nearest neighbor and bilinear
- Set operations
Basic relationships between pixels
  • Adjacency
  • Connectivity
  • Path

Basic relationships between regions
  • Adjacency
  • boundary

Distance measurement

Mathematical tools
  • Difference between matrix and array operation
  • Linear/nonlinear operation
  • Applications of image averaging, subtraction, and multiplication
Intensity Transformation

Log transformation

Power-law (gamma) transformation

Intensity level slicing

Applications and working conditions using these transformations
Histogram Processing

What is a histogram of an image?

Histogram equalization

Histogram matching
Spatial Filtering

Image convolution in spatial domain and has properties of

• Commutativity, Associativity, distributivity

Image correlation in spatial domain

Spatial filters

• Smoothing filter
  – Average filter
• Sharpening filter
  – Laplacian filter
  – Unsharp masking
  – Sobel operator
• Order-statistic filter
  – Median filter
  – Min/max filter
Fourier Transform

Fourier series

\[ f(t) = \sum_{n=-\infty}^{+\infty} c_n e^{\frac{j2\pi nt}{T}} \]

Unit impulse and its sifting property

\[ \int_{-\infty}^{\infty} f(t) \delta(t - t_0) dt = f(t_0) \]

Fourier transform

\[ F(\mu) = \int_{-\infty}^{\infty} f(t) e^{-j2\pi\mu t} dt \quad \leftrightarrow \quad f(t) = \int_{-\infty}^{\infty} F(\mu) e^{j2\pi\mu t} d\mu \]

Image convolution in frequency domain
Basic Properties of FT

**Linearity**  \[ h(t) = af(t) + bg(t) \Leftrightarrow H(u) = aF(u) + bG(u) \]

**Translation**  \[ h(t) = f(t - t_0) \Leftrightarrow H(u) = e^{-j2\pi t_0 u} F(u) \]

**Modulation**  \[ h(t) = e^{j2\pi u_0 t} f(t) \Leftrightarrow H(u) = F(u - u_0) \]

**Scaling**  \[ h(t) = f(at) \Leftrightarrow H(u) = \frac{1}{|a|} F\left(\frac{u}{a}\right) \]

**Conjugation**  \[ h(t) = f^*(t) \Leftrightarrow H(u) = F^*(-u) \]

**Symmetry**  \[ f(t) \Leftrightarrow F(\mu) \implies F(t) \leftrightarrow f(-u) \]
Image Degradation

\[ g(x, y) = h(x, y) \otimes f(x, y) + \eta(x, y) \]
\[ G(u, v) = H(u, v)F(u, v) + N(u, v) \]

Important noise models
- Gaussian noise model
- Impulse noise model

Image denoise
- Various mean filters and their applications
- Order-statistic filters and their applications

Image restoration
- Inverse filtering, Wiener filtering, and Constrained Least Square filtering
  - Working conditions
Fundamentals of color image processing

Primary/secondary colors
Primary/secondary pigments

Chromaticity: hue and saturation

Color gamut: any color on a line segment can be generated by two ending points; the same color can be generated by different combinations
Fundamentals of color image processing (Cont’d)

RGB model
CMYK model
HSI model

Requirement: how to represent a color in a specific model?
Color Transformation

For a color image with $n$ components

\[ s_i = T_i(r_1, r_2, \cdots, r_n), \quad i = 1, 2, \cdots, n \]

Intensity modification  \hspace{1cm} HSI model
Color complement  \hspace{1cm} RGB model
Tonal correction  \hspace{1cm} HSI model
Color balancing  \hspace{1cm} The choice of color model varies for a specific image
Histogram processing  \hspace{1cm} HSI model

Which model is the most effective to perform a specific transformation?