Lecture 4 (2.12.07)

Color and Multi-Spectral Images

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Lecture Outline

- Review of Lecture 3
- Visual Perception – Basics
- Color Representation
- Color Models
- Color Image Processing (Point & Kernel)
- Multi-spectral Images
Eye Physiology & Visual Perception

\[ I(x, y, \lambda) = r(x, y, \lambda)L(x, y, \lambda) \]
Rods & Cones Distribution in Retina

- **75~150 Million**
  - Sensitive to low illumination
  - Distributed over Retina
  - Scotopic (dim light) vision

- **6~7 Million**
  - Highly sensitive to color
  - Concentrated in Fovea
  - Photopic (day light) vision

Photoreceptor Cells
Visual Perception: Luminence

\[ I(x, y, \lambda) = r(x, y, \lambda)L(x, y, \lambda) \]

\[ F(x, y) = \int_0^\infty I(x, y, \lambda)V(\lambda)d\lambda \]

Luminance (intensity)
Visual Perception: Color

- Humans perceive only a few dozen gray levels but thousands of colors.

- Color perceptual attributes:
  - Brightness (perceived Luminence)
  - Hue (“redness”, “greenness”, …)
  - Saturation

\[
\begin{align*}
 C(\lambda) & \quad \int S_1(\lambda)C(\lambda)d\lambda \quad \alpha_1(C) \\
 & \quad \int S_2(\lambda)C(\lambda)d\lambda \quad \alpha_2(C) \\
 & \quad \int S_3(\lambda)C(\lambda)d\lambda \quad \alpha_3(C)
\end{align*}
\]

**FIGURE 6.3** Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.
Color Representation and Matching

**Young’s 3-color theory:**
Any color can be reproduced by mixing right amount of 3 primary colors

\[
\int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} P_k(\lambda) d\lambda = 1
\]

\[
\alpha_i(C) = \int \left[ \sum_{k=1}^{3} \beta_k P_k(\lambda) \right] S_i(\lambda) d\lambda = \sum_{k=1}^{3} \beta_k \int S_i(\lambda) P_k(\lambda) d\lambda
\]

\[
a_{i,k}^{\Delta} = \alpha_i(P_k) = \int S_i(\lambda) P_k(\lambda) d\lambda
\]

\[
\sum_{k=1}^{3} \beta_k a_{i,k} = \alpha_i(C) = \int S_i(\lambda) C(\lambda) d\lambda, \quad i = 1,2,3 \quad \Rightarrow \quad \beta_k \quad k = 1,2,3
\]
Color Representation

\[ C \rightarrow (T_1(C), T_2(C), T_3(C)) \]

Tri-stimulus representation of color C

\[ T_k(C) = \frac{\beta_k}{w_k} \]

Reference White:

\[ W(\lambda) = \sum_{k=1}^{3} w_k P_k(\lambda) \]

CIE standard

\[ P_1(\lambda) = \delta(\lambda - \lambda_1), \quad \lambda_1 = 700\text{nm, RED} \]
\[ P_2(\lambda) = \delta(\lambda - \lambda_2), \quad \lambda_2 = 546.1\text{nm, GREEN} \]
\[ P_3(\lambda) = \delta(\lambda - \lambda_3), \quad \lambda_3 = 435.8\text{nm, BLUE} \]
Chromaticity (= Hue & Saturation)

\[ t_k = \frac{T_k}{T_1 + T_2 + T_3}, \quad k = 1, 2, 3 \]

\((t_1, t_2, Y)\) completely define color space

Properties of the chromaticity diagram?
C.I.E. RGB $\rightarrow$ C.I.E. XYZ

- Yields positive tristimulus spectra
- Used for colormetric calculations
- MacAdam Ellipses

\[ \text{XYZ} \rightarrow \text{uvY} \]

- Transforms MacAdam Ellipses in XYZ to circles
CMY and CMYK

- Used in printers
- Primary pigment colors, secondary light colors
- Subtractive vs. Additive

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

- Intensity
- Hue
- Saturation
HSI Color Model

- Saturated colors on the outer points
- Max. saturation at intermediate intensity levels
- Distance between colors:

\[ D(C_1, C_2) = w_1 \Delta H + w_2 \Delta S + w_3 \Delta I \]

RGB → HSI
HSI → RGB
See GW pp. 299
Manipulation HSI images

- HSI values of primary and secondary colors
- HSI allows for independent manipulation of colors

- Hue of Green & Blue set to Zero
- Saturation of Cyan reduced by $\frac{1}{2}$
- Intensity of white reduced by $\frac{1}{2}$
Example: Image in different color-spaces representations
Pseudocoloring: Visualizing rainfall information

**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 America region. (Courtesy of NASA.)
Pseudocoloring: Visualizing blood flow pattern in the heart
Intensity Slicing:
Simple pseudocolor generation scheme

**FIGURE 6.18** Geometric interpretation of the intensity-slicing technique.
Gray-level $\rightarrow$ Color

![Functional block diagram for pseudocolor image processing](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 Harwitz, Westinghouse.)

**Figure 6.25** Transformation functions used to obtain the images in Fig. 6.24.
Gray-level $\rightarrow$ Color

FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.
Color Image Processing: Point vs. Kernel Processing

\[
f(x, y) = \begin{bmatrix} f_R(x, y) \\ f_G(x, y) \\ f_B(x, y) \end{bmatrix}
\]

\[
g(x, y) = T[f(x, y)]
\]

**FIGURE 6.29**
Spatial masks for gray-scale and RGB color images.
Multi-Spectral Image

<table>
<thead>
<tr>
<th>Channel</th>
<th>Wavelength band (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.40–0.44</td>
</tr>
<tr>
<td>2</td>
<td>0.62–0.66</td>
</tr>
<tr>
<td>3</td>
<td>0.66–0.72</td>
</tr>
<tr>
<td>4</td>
<td>0.80–1.00</td>
</tr>
<tr>
<td>5</td>
<td>1.00–1.40</td>
</tr>
<tr>
<td>6</td>
<td>2.00–2.60</td>
</tr>
</tbody>
</table>
Multi-Spectral Images

\[ x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{bmatrix} \]

FIGURE 11.27 Formation of a vector from corresponding pixels in six images.

<table>
<thead>
<tr>
<th>( \lambda_1 )</th>
<th>( \lambda_2 )</th>
<th>( \lambda_3 )</th>
<th>( \lambda_4 )</th>
<th>( \lambda_5 )</th>
<th>( \lambda_6 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3210</td>
<td>931.4</td>
<td>118.5</td>
<td>83.88</td>
<td>64.00</td>
<td>13.40</td>
</tr>
</tbody>
</table>

TABLE 11.5
Eigenvalues of the covariance matrix obtained from the images in Fig. 11.26.
Principle Component Analysis

\[
X = \begin{bmatrix}
x_1 \\
x_2 \\
\vdots \\
x_n \\
\end{bmatrix}
\]

\[
m_X = E\{X\} = \frac{1}{K} \sum_{k=1}^{K} X_k
\]

\[
C_X = E\{(X - m_X)(X - m_X)^T\} = \frac{1}{K} \sum_{k=1}^{K} X_k X_k^T - m_X m_X^T
\]

\[
Y = A(X - m_X)
\]

\[
A = [e_1, e_2, \ldots, e_n]
\]

\[
m_Y = 0
\]

\[
C_Y = AC_X A^T = \begin{bmatrix}
\lambda_1 & 0 \\
0 & \lambda_2 \\
\vdots & \ddots \\
0 & \cdots & \lambda_n
\end{bmatrix}
\]

eigen-vectors

eigen-values
Principle Component Images

*FIGURE 11.28* Six principal-component images computed from the data in Fig. 11.26. (Courtesy of the Laboratory for Applications of Remote Sensing, Purdue University.)
Color Coordinate Systems

- C.I.E. R,G,B
- C.I.E. X,Y,Z
- C.I.E. u,v,Y
- U*,V*,W*
- L*,a*,b*
- C,M,Y
- C,M,Y,K
- H,S,I
- Y,I,Q