Colour Balancing and Mapping

Rene Magritte, “The Empire of Lights”

CSC320: Introduction to Visual Computing
Michael Guerzhoy

Slides from Derek Hoiem, Robert Collins
Colour balancing

• Make objects have the colour in the photo that they have in the world (with neutral illumination)

Photos: http://www.kenrockwell.com/tech/whitebalance.htm
The original is in the middle. At left, white-balanced as if the dress is white-gold. At right, white-balanced to blue-black

•www.wired.com/2015/02/science-one-agrees-color-dress/
Important ideas

• Typical images are gray on average; this can be used to detect distortions

• Larger differences are more visible, so using the full intensity range improves visibility

• It’s often easier to work in a non-RGB color space
Colour balancing via linear adjustment

• Simple idea: multiply R, G, and B values by separate constants

\[
\begin{bmatrix}
\tilde{r} \\
\tilde{g} \\
\tilde{b}
\end{bmatrix} =
\begin{bmatrix}
\alpha_r & 0 & 0 \\
0 & \alpha_g & 0 \\
0 & 0 & \alpha_b
\end{bmatrix}
\begin{bmatrix}
r \\
g \\
b
\end{bmatrix}
\]

• How to choose the constants?
  – “Gray world” assumption: average value should be gray
  – White balancing: choose a reference as the white or gray color
  – Better to balance in camera’s RGB (linear) than display RGB (non-linear)
Tone Mapping

• Typical problem: compress values from a high range to a smaller range
  – E.g., camera captures 12-bit linear intensity and needs to compress to 8 bits
Limited Dynamic Range

**Range of Scene Luminance** (~$10^{-6}$ to $10^{+8}$ cd/m²)

- **starlight**: $10^{-6}$
- **moonlight**: $10^{-2}$
- **office light**: 1
- **daylight**: 10
- **flashbulb**: $10^{+8}$

**Sliding window**

- **Contrast range of human eye**: ~10,000:1
- **Contrast range of 8-bit sensor**: ~100:1
Limited Dynamic Range Can be Good
Example: Linear display of HDR (high dynamic range)

Scaled for brightest pixels

Scaled for darkest 0.1% intensities
Less “Strawmannish” Version

Underexposed (shutter too fast)  Oversaturated (shutter too slow)
Global operator (Reinhart et al.)

- Simple solution: map to a non-linear range of values

\[ L_{\text{display}} = \frac{L_{\text{world}}}{1 + L_{\text{world}}} \]
Reinhart Operator

Darkest 0.1% scaled to display device
Log transformations help with displaying Fourier Transforms

**FIGURE 3.5**
(a) Fourier spectrum.
(b) Result of applying the log transformation given in Eq. (3.2-2) with $c = 1$. 
Contrast Stretching

\[ T(r) \]

\[ \begin{align*}
& r_1, s_1 \\
& r_2, s_2 \\
& L/4 \\
& L/2 \\
& 3L/4 \\
& L - 1
\end{align*} \]

\[ \text{Input gray level, } r \]

\[ \text{Output gray level, } s \]

**Figure 3.10**
Contrast stretching.
(a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)
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Histogram equalization

• Basic idea: reassign values so that the number of pixels with each value is more evenly distributed

• Histogram: a count of how many pixels have each value

\[ h_i = \sum_{j \in \text{pixels}} 1(p_j == i) \]

• Cumulative histogram: count of number of pixels less than or equal to each value

\[ c_i = c_{i-1} + h_i \]
Image Histograms

Figure 3.15 Four basic image types: dark, light, low contrast, high contrast, and their corresponding histograms. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)
Histogram Equalization

**FIGURE 3.17** (a) Images from Fig. 3.15. (b) Results of histogram equalization. (c) Corresponding histograms.
Algorithm for global histogram equalization

Goal: Given image with pixel values \( 0 \leq p_j \leq 255 \), \( j = 0 \ldots N \)
specify function \( f(i) \) that remaps pixel values, so that the new values are more broadly distributed

1. Compute cumulative histogram: \( c(i), i = 0 \ldots 255 \)
   \[
   h(i) = \sum_{j \in \text{pixels}} 1(p_j == i), \; c(i) = c(i - 1) + h(i)
   \]

2. \( f(i) = \alpha \cdot \frac{c(i)}{N} \cdot 255 + (1 - \alpha) \cdot i \)
   
   – Blends between original image and image with uniform histogram
(Explanation on the blackboard)

- Explanation of histogram equalization