Color Constancy

• Color Constancy – interpretation of material colors independent of surrounding illumination.
Color Constancy

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Digital Images under Varying Illumination

• Cameras cannot adapt to varying illumination as humans do – images have a color cast depending on the light source.
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Color Temperature

- Color temperature of a light source is the temperature of an ideal black body radiator at which the color of the light source and the black body are identical.
Incandescent Light – Orange Color Cast
Moonlight – Blue Color Cast
Fluorescent Light : Green Color Cast
Color Balance

- Color Balance – adjusting the color components to eliminate color casts.
  - Chromatic Adaptation: estimation of representation of object as it would appear under a different light source than the one in which it was recorded.
- White Balance – aims to render neutral colors correctly to emulate the property of color constancy
• Color Balance – adjusting the color components to eliminate color casts.
• White Balance – aims to render neutral casts correctly to render visually pleasing images.

white balanced image
White Balance Tools

Digital Cameras
Auto White Balance
Gray Cards

White Balance Caps
• Take a picture of a neutral object (white or gray)

• Deduce the weight of each channel
  – If the object is recoded as \( R'_w, G'_w, B'_w \)
    use weights \( 1/R'_w, 1/G'_w, 1/B'_w \)

\[
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix} =
\begin{bmatrix}
255/R'_w & 0 & 0 \\
0 & 255/G'_w & 0 \\
0 & 0 & 255/B'_w
\end{bmatrix}
\begin{bmatrix}
R' \\
G' \\
B'
\end{bmatrix}
\]
Color Correction Filters
Mixed Lighting
Light Filters

Gel Filters

Light Filters
White Balance under Mixed Lighting

- Barnard [1997] – adaptation of gamut-based color constancy technique, Assumes smooth illumination

- Kawakami [2005] – outdoor scenes with hard shadows, illuminants restricted to black-body radiators
• Lischinski [2006] – user scribbles, correct localized color casts
Local Color Shift

Input Images:

Local Space Average Color:

Results
Light Mixture Estimation for Spatially Varying White Balance

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(Several slides from Eugene Hsu)
Algorithm Overview

- Recovers the dominant material colors and uses them to estimate the relative proportion of the two light colors at each of the pixels.

Input image illuminated by two light types
Voting scheme to recover dominant material colors in the scene.
Estimate light mixture at reliable pixels and interpolate missing values.
Estimated light mixture is used to achieve spatially varying white balance.
Assumptions

- Two light sources – specified by the user

- Interaction of light can be described using RGB channels only

- Surfaces are Lambertian and non-fluorescent - which implies that the image color is the product of illumination and reflectance.

- Color bleeding due to indirect illumination can be ignored
Image Formation Model

\[ I_R \quad I_G \quad I_B = \quad R_R \quad R_G \quad R_B \quad \cdot \quad k \quad L_R \quad L_G \quad L_B \]

Observed pixel color is material color multiplied by scaled light color.
Proper white balance is achieved by inverting the effect of the light source color.
Proper white balance is achieved by inverting the effect of the light source color.
Image model with two light sources
Proper white balance can be achieved if the relative proportion of the two light sources is known.
\[ \alpha = \frac{k_1}{k_1 + k_2} \]

Solving for \( \alpha \) is under-constrained since the actual material colors are not given.
Material Color Estimation

- Assume scene is dominated by a small set of material colors, hence reflectance spectra is sparse.
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• Assume scene is dominated by a small set of material colors, hence reflectance spectra is sparse.

\[
\begin{align*}
I_R & \quad R_R \\
I_G & \quad R_G \\
I_B & \quad R_B
\end{align*}
\]

\[
\begin{pmatrix}
I_R \\
I_G \\
I_B
\end{pmatrix}
= 
\begin{pmatrix}
R_R \\
R_G \\
R_B
\end{pmatrix}
\cdot
\begin{pmatrix}
L_R \\
L_G \\
L_B
\end{pmatrix}
\]
Material Color Estimation

- Assume scene is dominated by a small set of material colors, hence reflectance spectra is sparse.

\[
\begin{align*}
I_R & = R_R \\
I_G & = R_G \\
I_B & = R_B \\
\end{align*}
\]

\[
\begin{pmatrix}
L_R \\
L_G \\
L_B \\
\end{pmatrix}
= \begin{pmatrix}
R_R \\
R_G \\
R_B \\
\end{pmatrix} \cdot k
\]

Scene viewed in white light
Material Color Estimation

- Assume scene is dominated by a small set of material colors, hence reflectance spectra is sparse.

\[
\begin{bmatrix}
I_R \\
I_G \\
I_B
\end{bmatrix}
= \begin{bmatrix}
R_R \\
R_G \\
R_B
\end{bmatrix}
\cdot \begin{bmatrix}
L_R \\
L_G \\
L_B
\end{bmatrix}
\]

Scene viewed in mixed light
Sample material colors and find the one that accounts for the observed color of most pixels.
Given a candidate material color…
\[ I = R \cdot (k_1 L_1 + k_2 L_2) \]

...a pixel votes for a material color only if the observed color can be explained by a combination of given light sources.
If this expression holds, we say that the pixel votes for the material color.

\[ t \geq \min \| I - R \cdot (k_1L_1 + k_2L_2) \| \]
Light mixture estimation for reliable pixels
Mixture Interpolation

\[
\begin{align*}
I_R & = R_R \\
I_G & = R_G \\
I_B & = R_B
\end{align*}
\]

Assume \( L_{1B} \) and \( L_{2B} \) are 1, divide out the blue channels.

\[
\begin{align*}
I_{R\div B} & = R_{R\div B} \\
I_{G\div B} & = R_{G\div B}
\end{align*}
\]

This looks exactly like Image Matting.
Interpolation is performed using Matting Laplacian
[Levin et al. 2006]
Scene shot with multiple exposures so that ground truth is available.
Constraint the marked points and interpolate the rest
Smooth interpolation is pretty bad.
Edge-aware interpolation doesn’t work satisfactorily either.
Matting Laplacian gives much better result.
Experiments – Synthetic Data

Input
Experiments – Real Data
Input

LME

Local Color Shift
LME                                          Local Color Shift
Scene Relighting

Separate the two lighting contributions from the white Balanced image
The observed scene is a blend of two images as seen by either of the light sources in proportions $\alpha$ and $1-\alpha$.

\[
\begin{bmatrix}
R_R & 1 & 1 \\
R_G & k_1 & 1 \\
R_B & 1 & 1 \\
\end{bmatrix} \cdot \begin{bmatrix}
1 & 1 \\
k_2 & 1 \\
1 & 1 \\
\end{bmatrix} \cdot \alpha \cdot \begin{bmatrix}
k_1 \\
+k_2 \\
\end{bmatrix}
\]

Multiply the white balanced image by $\alpha$ for the first contribution.
Multiply the white balanced image by $\alpha$ for the first Contribution and by $1-\alpha$ for the second contribution.
We can choose new lights and add desired effects.
Input
Discussion

• Works best for raw image data

• Better results for indoor scenes

• Handles specularities and inter-reflections

• Material colors should exhibit enough color variation for the voting to work.

• Accurate specification of light sources is required.

• Scalability Issues