Automatic white balancing via gray surface identification

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Abstract

◆ Automatic white balancing of digital imagery
  – estimate accurately the color of the overall scene illumination

◆ Gray world assumption
  – Simplest and quite widely used

◆ Proposed method
  – Borrowing on some of strengths and simplicity of the gray world algorithm
  – Significantly improvement on its performance while adding little to its complexity
Introduction

◆ Key to automatic white balancing of digital imagery
  – estimate accurately the color of the overall scene illumination

◆ Gray world algorithm
  – Based on the assumption
    • The average surface color in a scene is gray so that when an image’s colors are averaged, any departure from gray reflects the color of the scene illumination

◆ Proposed extension
  – Identifies colors likely to be from truly gray surfaces
  – Averages only those colors
The goal

- To represent 3 components of a color
  - In terms of the underlying physical components that generated the color
  - Luminance/intensity, incident illumination color, and the surface reflectance color
- In experiment
  - LIS channel shows
    - Points in it having an S coordinate of zero were generally gray
    - Not gray in RGB space
Strategy for the proposed new automatic white balance (AWB)
- To use the LIS coordinates to identify gray surfaces
- Estimate the illuminant color
- Convert back to the original RGB color space
- Average the chromaticities of the grays
Two assumptions of LIS coordinates

- Illuminants are blackbody radiators
- Camera’s response functions are narrowband and can be modeled as Dirac delta functions.

GSI (gray surface identification)

Fig. 1. (a) Input image; (b) Pixels identified as gray are indicated in white.
Implication for two assumptions

- Illuminants can be modeled as a function of a single parameter
  - Blackbody temperature
- Each of the RGB channels is affected by only a single distinct wavelength of the incoming spectrum
Finlayson and Hordley

- Illumination-invariant color chromaticity space
  - For a given camera
    - $\log R/G$, $\log B/G$
  - Values of same surface under various illuminations
    - Tend to fall on a straight line and lines from different surfaces are parallel
  - For fixed surface reflectance
    - Varying the intensity and color temperature of the illumination incident
    - Causes the logarithm of the camera response [$\log R$, $\log G$, $\log B$] to move within a plane.
Blackbody-radiator and dirac-delta assumptions

- For \([\log R, \log G, \log B]\) data synthesized based on the SONY DXC-930 sensitivity functions
- 102 illuminant spectra from the Simon Fraser University database
- Surface reflectance of the 24 Macbeth Colorchecker
- PCA (principal component analysis) determines the plane
- Establish that the first 2 dimensions explain 99.1% percent of the variance
- These 102 illuminants are not specifically blackbody radiators
– Common light sources found around a university campus similarly
  • Camera sensitivity functions are relatively sharp with little overlap between them, they are taken from a real camera
  • Certainly violate the Dirac-delta assumption
– Despite violating the assumptions,
  • Fit of a plane to the data is surprisingly good
First issue for GSI color constancy algorithm

- LIS system is camera dependant and must be determined for the camera being used
- Camera’s spectral sensitivity response functions are known
  - Calculate camera responses for spectra synthesized as the product of illuminant and reflectance spectra chosen from a database of spectra
- Camera’s spectral sensitivity response functions are unknown
  - Real values can be obtained by using the camera to take images of a gray card under several different illuminants
  - PCA is then applied to the logarithm of RGBs from the gray card
◆ GSI method
- Estimates the color \([Re, Ge, Be]\) of an image’s illumination

\[
\begin{align*}
R_e &= \frac{1}{N} \sum_i w_i R_i \\
G_e &= \frac{1}{N} \sum_i w_i G_i \quad \text{if } isgray ([R_i, G_i, B_i]) \text{ then } w_i = 1 \text{ else } w_i = 0 \\
B_e &= \frac{1}{N} \sum_i w_i B_i
\end{align*}
\]

where ‘isgray’ is the test that classifies pixels as gray or not
Experiments

- Implemented in MATLAB 7.0.1
  - To evaluate GSI’s illumination estimation and compare it to other methods
  - Testing on two datasets of real images
    - 321 images of the SFU dataset which are of scenes in a laboratory setting
    - Much larger and more varied image collection that Ciurea et. al. built using a digital video camera
Error measures

- Based on Euclidean distance and angular difference between the estimated and true illumination chromaticity values

\[ r_e = \frac{R_e}{R_e + G_e + B_e}, g_e = \frac{G_e}{R_e + G_e + B_e}, b_e = \frac{B_e}{R_e + G_e + B_e} \]

\[ E_{i\text{-dist}} = \sqrt{(r_r - r_e)^2 + (g_r - g_e)^2} \]

\[ E_{i\text{-angular}} = \cos^{-1} \left[ \frac{(r_r, g_r, b_r) \cdot (r_e, g_e, b_e)}{\sqrt{r_r^2 + g_r^2 + b_r^2} \sqrt{r_e^2 + g_e^2 + b_e^2}} \right] \times \frac{2\pi}{360} \]

\[ \text{RMS}_{\text{dist}} = \frac{1}{N} \sqrt{\sum_{i=1}^{N} E_{i\text{-dist}}^2} \]

\[ \text{RMS}_{\text{angular}} = \frac{1}{N} \sqrt{\sum_{i=1}^{N} E_{i\text{-angular}}^2} \]
Original image database including 11,346 images
- Eliminating from the data set the majority of the correctly balanced images
  - overall distribution of the illumination color is more uniform
- Resulting data set contains 7661 images

Figure 2. (a) The original data set contains 11,346 images, but the illumination chromaticities cluster around gray (0.33, 0.33). (b) The reduced data set contains 7661 images with a more uniform distribution of illumination chromaticity.
Cropped images

- To remove the gray ball, which is located at a fixed location in the lower right quadrant

Figure 3. (a) Original image containing gray ball from which the color of the scene illumination is determined. (b) Cropped image to be used for algorithm testing with gray ball removed.
Table 1. Comparison of GSI performance to that of 2D and 3D Support Vector Regression, Shades of Grey, Max RGB, and Grayworld. The results involve real-data training and testing on the 321 SONY images. Errors are based on leave-one-out cross-validation evaluation and are reported in terms of both the RMS angular chromaticity and distance error measures.

<table>
<thead>
<tr>
<th>Method</th>
<th>SVR Dimension/ Norm Power</th>
<th>Median Angle</th>
<th>RMS Angle</th>
<th>Max Angle</th>
<th>Median Dist(×10^2)</th>
<th>RMS Dist (×10^2)</th>
<th>Max Dist (×10^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSI</td>
<td></td>
<td>3.91</td>
<td>10.11</td>
<td>33.79</td>
<td>2.71</td>
<td>7.15</td>
<td>22.65</td>
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<tr>
<td>SVR 2D</td>
<td></td>
<td>4.65</td>
<td>10.06</td>
<td>22.99</td>
<td>3.41</td>
<td>7.5</td>
<td>16.41</td>
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<tr>
<td>SVR 3D</td>
<td></td>
<td>2.17</td>
<td>8.069</td>
<td>24.66</td>
<td>3.07</td>
<td>6.3</td>
<td>16.03</td>
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<tr>
<td>SoG 6</td>
<td></td>
<td>3.97</td>
<td>9.027</td>
<td>28.70</td>
<td>2.83</td>
<td>6.21</td>
<td>19.77</td>
</tr>
<tr>
<td>Max RGB</td>
<td></td>
<td>6.44</td>
<td>12.28</td>
<td>36.24</td>
<td>4.46</td>
<td>8.25</td>
<td>25.01</td>
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<tr>
<td>GW</td>
<td></td>
<td>7.04</td>
<td>13.58</td>
<td>37.31</td>
<td>5.68</td>
<td>11.12</td>
<td>35.38</td>
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Table 2. Comparison of the different algorithms based on Wilcoxon signed-rank test on 321 images. A ‘+’ means the algorithm listed in the corresponding the row is better than the one in corresponding column; a ‘-‘ indicates the opposite; an ‘=’ indicates that the performance of the respective algorithms is statistically equivalent.

<table>
<thead>
<tr>
<th></th>
<th>GSI</th>
<th>2D SVR</th>
<th>3D SVR</th>
<th>SoG (norm power = 6)</th>
<th>Max RGB</th>
<th>GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSI</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>2D SVR</td>
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<tr>
<td>3D SVR</td>
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<td></td>
</tr>
<tr>
<td>SoG (norm power = 6)</td>
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<td></td>
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<tr>
<td>Max RGB</td>
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<tr>
<td>GW</td>
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</table>
Table 3. Comparison of GSI error to 3D SVR, SoG, Max RGB, and Grayworld. The results involve real-data training and testing on disjoint sets of 7,661 images taken from the Ciurea data set.

<table>
<thead>
<tr>
<th>Method</th>
<th>Angular Degrees</th>
<th>Distance ($ \times 10^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>RMS</td>
</tr>
<tr>
<td>GSI</td>
<td>5.46</td>
<td>7.95</td>
</tr>
<tr>
<td>3D SVR</td>
<td>4.91</td>
<td>7.03</td>
</tr>
<tr>
<td>SoG</td>
<td>6.71</td>
<td>8.93</td>
</tr>
<tr>
<td>MAX RGB</td>
<td>9.65</td>
<td>12.13</td>
</tr>
<tr>
<td>GW</td>
<td>6.82</td>
<td>9.66</td>
</tr>
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</table>

Table 4. Algorithm comparison using the Wilcoxon signed-rank test for real-data training and testing on disjoint sets of 7,661 images from the Ciurea data set. Labeling ‘+’, ‘-‘, ‘=’ as for Table 2.

<table>
<thead>
<tr>
<th>Method</th>
<th>GSI</th>
<th>3D SVR</th>
<th>SoG (norm power = 6)</th>
<th>MAX</th>
<th>GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSI</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3D SVR</td>
<td>+</td>
<td>-</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SoG (norm power = 6)</td>
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<tr>
<td>MAX</td>
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<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>GW</td>
<td>-</td>
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</tbody>
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A new color constancy method, GSI
- Based on detecting pixels corresponding to gray surface reflectance
- Using their average image color as an indicator of the color of the overall scene illumination

Gray surfaces
- Find by first transforming the image RGB values to the LIS coordinate system with luminance, illumination ‘color’ and reflectance

Tests on real images
- Show the GSI method works better than Shades of Gray, Grayworld and Max RGB