Exemplar-Based Color Constancy and Multiple Illumination


Hamid Reza Vaezi Joze and Mark S Drew

Presented by Shibudas Kattakkalil Subhashdas

School of Electronics Engineering, Kyungpook National University
Introduction

- Proposed Method
  - It consists of three stages
    - Surface modeling
    - Illumination Estimation
    - Color correction
Introduction

Related Work

- Static methods
  - White-Patch or Max-RGB method
  - Grey-World Hypothesis
  - Grey-Edge Hypothesis

- Learning based methods
  - Gamut Mapping algorithm
Introduction

- Max-RGB
  - Illuminant
    \[
    \left[ R_E, G_E, B_E \right]' = \left[ \max(R_{in}), \max(G_{in}), \max(B_{in}) \right]
    \]
  - Output RGB value
    \[
    \left[ R_{out}', G_{out}', B_{out}' \right] = \left[ \alpha R_{in}', G_{out}', \beta B_{in}' \right]
    \]
    \[
    \alpha = \frac{G_E}{R_E}, \quad \beta = \frac{G_E}{B_E}
    \]
Proposed Method

- Surface Modeling (Training Image)
  - Segmentation
    - Mean Shift segmentation
Proposed Method

- Surface Modeling (Training Image)
  - Texture and color features are used to define a model to each segmented surface.
  - MR8 filter is used for texture feature
    - Filter bank consists of 38 filters (6 orientations at 3 scales or 2 oriented/anisotropic filters, plus 2 isotropic).

The MR8 filter bank consists of 2 anisotropic filters (an edge and a bar filter, at 6 orientations and 3 scales), and 2 rotationally symmetric ones (a Gaussian and a Laplacian of Gaussian).
Proposed Method

- Surface Modeling (Training Image)
  - MR8 filter is used for texture feature
    - Records only the maximum filter response over each filter response from all orientation (8 filter response)

The MR8 filter bank consists of 2 anisotropic filters (an edge and a bar filter, at 6 orientations and 3 scales), and 2 rotationally symmetric ones (a Gaussian and a Laplacian of Gaussian).
Proposed Method

- Surface Modeling (Training Image)
  - Texture feature
    - Generate Texton dictionary
    - Represent each texture with a 8 dimensional data (Filter response)
    - Cluster texture in 1000 clusters (KNN)
Proposed Method

- Surface Modeling (Training Image)
  - Segmentation
    - Mean Shift segmentation
Proposed Method

- Surface Modeling (Training Image)
  - Texture feature
    - Texton histogram for all training image surface

- Apply MR8 Filter each pixel in Selected surface
- Compare filter response with each cluster

- Texton histogram (Normalized)
Proposed Method

- Surface Modeling (Training Image)
  - Color feature
    - Color constant diagonal transformation matrix generated by Max-RGB method for each surface model.
      - Color constant diagonal transformation matrix ($M$)
        
        \[
        M = \begin{bmatrix}
        \alpha & 0 & 0 \\
        0 & 1 & 0 \\
        0 & 0 & \beta \\
        \end{bmatrix}
        \]

        \[
        \beta = \frac{G_{\text{max}}}{B_{\text{max}}} \quad \alpha = \frac{G_{\text{max}}}{R_{\text{max}}} 
        \]
Proposed Method

Surface Modeling (Training Image)

- Color feature
  - Normalized histogram of R, G and B for each surface model (10 bins for each channel)
Proposed Method

- Surface Modeling (Training Image)
  - For each surface model in training image represented with
    - Normalized texton histogram,
    - Normalized R, G and B histogram
    - Color constant diagonal transformation matrix ($M$)
    - Ground truth illumination color.
Proposed Method

- Surface Modeling (Test Image)
  - Apply MR8 Filter each pixel in Selected surface
  - Compare filter response with each cluster
Proposed Method

- Surface Modeling
  - Test image surface model is then compared all the training image surface by nearest neighbor classifier.
  - Select M nearest neighbor from training image. (M=10)
Proposed Method

**Illuminant Estimation**

- Matrix (D) which transform test surface to training surface
  \[
  D = M_{test}^{-1} D_H M_{train}
  \]
  
  - \(M_{test}\) and \(M_{train}\) are the Color constant diagonal transformation matrix of the test and train surface
  - \(D_H\) is the transformation of the test surface’s histograms to training surfaces' histogram
- Test surface illumination color \(e_{test}\)
  \[
  e_{test} = D e_{train} = M_{test}^{-1} D_H M_{train} e_{train}
  \]
Proposed Method

- **Illuminant Estimation**
  - Given test image has
    - N large enough surfaces
    - M nearest neighbor surfaces from training data or equally M illumination estimates.
  - Final estimate can be the median or mean of these estimates in \( r-g \) chromaticity space.
Proposed Method

- **Color Correction**
  - The Color correction using estimated back-projection.
    \[
    I_{ijk}^* = I_{ij} \times \frac{e_k^*}{D_{ijk}} \quad k = \{R,G,B\}
    \]
  - When uniform illumination assumption is made, the back propagation is constant
    \[
    I_{ijk}^* = I_{ij} \times e_k^* \quad k = \{R,G,B\}
    \]
Proposed Method

☐ Evaluation

- Angular error

\[ err_{angle} = a \cos \frac{e \cdot e_{est}}{\|e\| \|e_{est}\|} \]

✓ \( e \) - chromaticity of actual illuminant
✓ \( e_{est} \) - chromaticity of estimated illuminant
## Experiment Results

<table>
<thead>
<tr>
<th>Original</th>
<th>Exemplar-based</th>
<th>Grey-World</th>
<th>Grey-Edge</th>
<th>Gamut Mapping</th>
<th>Zeta</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Original Image" /></td>
<td><img src="image2" alt="Exemplar-based Image" /></td>
<td><img src="image3" alt="Grey-World Image" /></td>
<td><img src="image4" alt="Grey-Edge Image" /></td>
<td><img src="image5" alt="Gamut Mapping Image" /></td>
<td><img src="image6" alt="Zeta Image" /></td>
</tr>
<tr>
<td><img src="image1" alt="Original Image" /></td>
<td><img src="image2" alt="Exemplar-based Image" /></td>
<td><img src="image3" alt="Grey-World Image" /></td>
<td><img src="image4" alt="Grey-Edge Image" /></td>
<td><img src="image5" alt="Gamut Mapping Image" /></td>
<td><img src="image6" alt="Zeta Image" /></td>
</tr>
<tr>
<td><img src="image1" alt="Original Image" /></td>
<td><img src="image2" alt="Exemplar-based Image" /></td>
<td><img src="image3" alt="Grey-World Image" /></td>
<td><img src="image4" alt="Grey-Edge Image" /></td>
<td><img src="image5" alt="Gamut Mapping Image" /></td>
<td><img src="image6" alt="Zeta Image" /></td>
</tr>
<tr>
<td><img src="image1" alt="Original Image" /></td>
<td><img src="image2" alt="Exemplar-based Image" /></td>
<td><img src="image3" alt="Grey-World Image" /></td>
<td><img src="image4" alt="Grey-Edge Image" /></td>
<td><img src="image5" alt="Gamut Mapping Image" /></td>
<td><img src="image6" alt="Zeta Image" /></td>
</tr>
</tbody>
</table>
Experiment Results

- **Comparison**
  - **Gray ball dataset**
    - | Method                  | Original ColorChecker | Reprocessed ColorChecker |
    |------------------------|-----------------------|--------------------------|
    |                        | Median | Mean | 75th | Median | Mean | 75th | Median | Mean | 75th |
    | Do nothing             | 6.8°   | 9.5° | 13.6° | 13.5°   | 13.4° | 14.8° |
    | White-Patch            | 6.0°   | 8.1° | 10.8° | 5.7°    | 7.4°  | 11.7° |
    | Grey-World             | 7.3°   | 9.8° | 14.6° | 6.3°    | 6.4°  | 8.4°  |
    | Grey-Edge              | 5.2°   | 7.0° | 9.5°  | 4.5°    | 5.3°  | 7.0°  |
    | Zeta-Image [22]        | 5.0°   | 6.9° | 9.0°  | 2.8°    | 4.1°  | 5.6°  |
    | Bayesian               | 4.7°   | 6.7° | 8.8°  | 3.5°    | 4.8°  | 6.7°  |
    | Gamut Mapping          | 4.9°   | 6.9° | 8.9°  | 2.5°    | 4.1°  | 6.0°  |
    | Gamut Mapping 1jet [24]| 4.9°   | 6.9° | 9.0°  | 2.5°    | 4.1°  | 6.0°  |
    | Spatio-spectral Statistics ML [30]| - | - | - | 3.0°    | 3.7°  | 4.9°  |
    | Bottom-up+Top-down [37]| 4.5°   | 6.4° | 8.8°  | 2.5°    | 3.5°  | 4.1°  |
    | Natural Image Statistics| 4.5°  | 6.1° | 8.2°  | 3.1°    | 4.2°  | 5.8°  |
    | Exemplar-Based        | 3.7°   | 5.2° | 7.0°  | 2.3°    | 3.1°  | 3.9°  |
  
- **Color checker dataset**
    - | Method                  | Original GrayBall | Linear GrayBall |
    |                        | Median | Mean | 75th | Median | Mean | 75th | Median | Mean | 75th |
    | Do nothing             | 6.7°   | 8.3° | 14.0° | 14.0°   | 15.6° | 20.5° |
    | White-Patch            | 5.3°   | 6.8° | 10.4° | 10.5°   | 12.7° | 19.5° |
    | Grey-World             | 7.0°   | 7.9° | 10.8° | 11.0°   | 13.0° | 20.2° |
    | Grey-Edge              | 4.7°   | 5.9° | 8.6°  | 8.8°    | 10.6° | 15.0° |
    | Zeta-Image [22]        | 4.6°   | 5.9° | 8.6°  | 9.0°    | 10.8° | 15.0° |
    | Gamut Mapping          | 5.8°   | 7.1° | 10.2° | 8.9°    | 11.8° | 18.0° |
    | Gamut Mapping 1jet [24]| 5.8°   | 6.9° | 9.6°  | 8.9°    | 11.8° | 17.5° |
    | Spatio-spectral Statistics ML [30]| - | - | - | 8.9°    | 10.3° | 13.9° |
    | Bottom-up+Top-down [37]| -     | -   | -    | 7.7°    | 9.7°  | 13.3° |
    | Natural Image Statistics [32]| 3.9°  | 5.2° | 7.4°  | 7.7°    | 9.9°  | 13.8° |
    | Exemplar-Based        | 3.3°   | 4.4° | 6.1°  | 6.5°    | 8.0°  | 10.8° |
## Experiment Results

### Comparison
- Multi-illuminant outdoor dataset

<table>
<thead>
<tr>
<th>No. of Illuminants</th>
<th>Method</th>
<th>Median Err.</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>White-Patch</td>
<td>7.8°</td>
</tr>
<tr>
<td></td>
<td>Grey-World</td>
<td>8.9°</td>
</tr>
<tr>
<td></td>
<td>Grey-Edge (n=1)</td>
<td>6.4°</td>
</tr>
<tr>
<td></td>
<td>Grey-Edge (n=2)</td>
<td>5.0°</td>
</tr>
<tr>
<td>Two (from [47])</td>
<td>White-Patch</td>
<td>6.7°</td>
</tr>
<tr>
<td></td>
<td>Grey-World</td>
<td>6.4°</td>
</tr>
<tr>
<td></td>
<td>Grey-Edge (n=1)</td>
<td>5.6°</td>
</tr>
<tr>
<td></td>
<td>Grey-Edge (n=2)</td>
<td>5.1°</td>
</tr>
<tr>
<td>One Two Multi</td>
<td>Exemplar-Based</td>
<td>5.1°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.8°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.3°</td>
</tr>
</tbody>
</table>
Proposed Method

- Color Correction

  - For non-constant back projection, Mask map $m_j(x)$ is used

\[
m_j(x) = \frac{d'_j(x)}{\sum_{k=1}^{N} d'_j(x)} \quad d'_j(x) = \frac{\sum_x d_j(x)}{d_j(x)}
\]

$d_j(x)$ - Chromatic distance of the estimated illuminant of the patch located at spatial coordinate $x$ in the image to the $j^{th}$ illuminant.