Color Gamut Mapping Algorithm for Preserving Spatial Ratios

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Abstract

- Calculation algorithm for a spatial gamut mapping
  - Concretizes McCann’s method
  - Preserves spatial ratio from only the input image
  - Uses the relaxation labeling technique
Introduction

◆ Gamut mapping algorithm
  – Optimum color reproduction
  – Suitable trade-off
    • Contrast, luminance detail, vividness, and smoothness
◆ History
  – Non-adaptive pointwise
  – Appropriate GMA to the image gamut
  – Preservation of the image detail
  – Account the spatial and color characteristics of image
Recent trends

– McCann
  • Preserves ratios of colors at adjacent pixels
  • Reproduces more like the original

Proposed method

– Image quality enhancement
  • Preserves spatial ratio from only an input image
– Use combinatorial optimization problem and relaxation labeling technique
GMA to preserve spatial ratio

- **Definition**
  - “*area*” as A to Q of each color pentagon
  - “*edge*” as 1 to 32 of boundary of the adjacent area

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**Fig. 1.** Original Mondrian pattern

**Fig. 2.** Definition of area name and edge number.
McCann’s method

- Preserves the ratios at adjacent edges for each XYZ
- Optimization problem

$$\Delta R = \text{average}_{i,j}$$

$$\sqrt{\left(1 - \frac{X^{(i)}_{\text{Rep}} / X^{(j)}_{\text{Rep}}}{X^{(i)}_{\text{Ori}} / X^{(j)}_{\text{Ori}}} \right)^2 + \left(1 - \frac{Y^{(i)}_{\text{Rep}} / Y^{(j)}_{\text{Rep}}}{Y^{(i)}_{\text{Ori}} / Y^{(j)}_{\text{Ori}}} \right)^2 + \left(1 - \frac{Z^{(i)}_{\text{Rep}} / Z^{(j)}_{\text{Rep}}}{Z^{(i)}_{\text{Ori}} / Z^{(j)}_{\text{Ori}}} \right)^2},$$

Where $X^{(i)}_{\text{Ori}}, Y^{(i)}_{\text{Ori}}, Z^{(i)}_{\text{Ori}}$ and $X^{(i)}_{\text{Rep}}, Y^{(i)}_{\text{Rep}}, Z^{(i)}_{\text{Rep}}$ mean the tristimulus values at area $i$ in an original and gamut mapped reproduction image, respectively, and $X^{(j)}, Y^{(j)}$ and $Z^{(j)}$ are the tristimulus values of an adjacent area $j$ of the area $i$. 
• Subject
  - $X_{Rep}, Y_{Rep}, Z_{Rep}$ exist within the gamut of the reproduction media
  - ill-posed problem due to infinite solutions

\[
\left( X^{(i)}_{Rep}, Y^{(i)}_{Rep}, Z^{(i)}_{Rep} \right) = \kappa \left( X^{(i)}_{Ori}, Y^{(i)}_{Ori}, Z^{(i)}_{Ori} \right), \forall i
\]  

(2)

Where $\kappa$ is a scaling factor in real number.

• Problems
  - Remarkable decrease in luminance and chroma due to one greatly away pixel
    » Compresses the whole pixels

Needs local optimum solution
Gamut calculation by relaxation labeling

- Proposed method
  - Gamut calculation algorithm using the relaxation labeling
    - Optimization technique for solving labeling problems
      - Decomposition of a complex computation into a network of simple “myopic” or local
      - Requisite use of context in resolving ambiguities
– Evaluation of the adjacent ratio

• Labeling problem
  – A set of objects *(areas)*;  \( O = \{ o_i \}_{i=0}^{I-1}, \ I = 17 \)
  – A set of labels for each object *(Y stimulus)*;  \( \Lambda_i = \{ \lambda_k^{(i)} \}_{k=0}^{K-1}, \ K = 100 \)
    » \( Y \) as \( K \)-th quantized discrete values in range \([0-100]\)
  – A neighbor relation over the objects;
  – A constraint relation over labels at pairs (or n-tuples) of neighboring objects.
• Finds the most matches \( Y \) stimulus \((\lambda_k^{(i)})\) for each \( O_i \)

- Let \( P_{i(k)}^{(t)} \): \( t \)-time developed probability for classification of object \( O_i \) into \( \lambda_k^{(i)} \)

\[
0 \leq P_{i(k)}^{(t)} \leq 1, \quad \forall i, k,
\]

\[
\sum_{k=0}^{K-1} P_{i(k)}^{(t)} = 1, \quad i = 0, 1, \ldots, I - 1.
\]

- Start **iterative processing** and update probabilities to minimize the objective function in eq.(1)

\[
P_{i(k)}^{(t+1)} = \frac{P_{i(k')}^{(t)} \times q_{i(k)}^{(t)}}{\sum_{k'} P_{i(k')}^{(t)} \times q_{i(k')}^{(t)}}.
\]

» Compatibility function(CF)

\[
q_{i(k)}^{(t)} = \sum_{o_j \in N_i} \left\{ \max_{\lambda^{(i)}_l} r_{ij(k,l)} \times P_{i(k)}^{(t)} \right\}
\]

Where \( N_i \) is a set of neighboring objects of \( o_j \in N_i \) into possible labels \( \Lambda_j = \{\lambda^{(j)}_i\}_{i=0}^{L-1} \).
» Compatibility coefficient, $r_{ij(k,l)}$

- How the classification of $o_i$ into $\lambda_k^{(i)}$ with the classification of $o_j$ into $\lambda_l^{(j)}$.

- if the neighboring objects support the classification of $o_i$ and $\lambda_k^{(i)}$ the CF $q^{(i)}_{i(k)}$ must be high in the framework of the relaxation labeling.

$$r_{ij(kl)} = \max\left(0, \alpha - \left|1 - \frac{\lambda_k^{(i)}}{\lambda_l^{(j)}}\right|\right), \quad \alpha > 0 (\alpha = 2) \quad (7)$$

Where $\alpha$ is a sensitive parameter for evaluating the difference of the ratio.

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Evaluates the objective function in eq(1) locally
- Reduction of local ambiguities and achievement global consistency

- $r_{ij(kl)}$ become max $\alpha$ for the same ratio between original and reproduction image

- $r_{ij(kl)}$ become max $\alpha$ for the same ratio between original and reproduction image
- T-time iteration performance
  » Obtains a $Y$ stimulus $\lambda_{k_i}^{(i)}$ with maximum probability $P_{i(k_i)}^{(T)}$ for each area $x_i$

\[
Y_{rep}^{(i)} = \lambda_{k_i}^{(i)}
\]  

(8)

» Calculates $X_{rep}^{(i)}$ and $Z_{rep}^{(i)}$ with preserving ratio

\[
\begin{cases}
X_{rep}^{(i)} = X_{org}^{(i)} \cdot \left( \frac{Y_{rep}^{(i)}}{Y_{org}^{(i)}} \right) \\
Z_{rep}^{(i)} = Z_{org}^{(i)} \cdot \left( \frac{Y_{rep}^{(i)}}{Y_{org}^{(i)}} \right)
\end{cases}
\]

(9)
Gamut mapping to narrow gamut
  - Uses DLP having smaller gamut with sRGB
  - Initial probabilities
    • If the area color exist in the gamut, use original intensity

Fig. 3. Color gamut of the DLP projector (solid) and sRGB (wire).

Fig. 4. Set of initial probabilities.
Fig. 5. Gamut mapping results.
Spatial metrics

- $\Delta R$

- $\Delta L = \text{average}_{ij} \left| 1 - \frac{L_{rep}^*(i) / L_{rep}^*(j)}{L_{ori}^*(i) / L_{ori}^*(j)} \right|$

Fig. 6. Results for 32 edge XYZ ratios in Experiment 1.
<table>
<thead>
<tr>
<th></th>
<th>$\Delta R$</th>
<th>$\Delta L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial pattern</td>
<td>0.80</td>
<td>0.18</td>
</tr>
<tr>
<td>Reproduction pattern</td>
<td>0.13</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Fig. 7. Results for 32 edge luminance ratios in Experiment 1.
Gamut mapping to wide gamut - Experiment 2 -

Fig. 8. Color gamut of the LCD monitor (Adobe RGB).

Table. 2. Evaluation for spatial ratio in Experiment 2.

<table>
<thead>
<tr>
<th></th>
<th>$\Delta R$</th>
<th>$\Delta L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial pattern</td>
<td>1.28</td>
<td>0.31</td>
</tr>
<tr>
<td>Reproduction</td>
<td>0.05</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Fig. 9. Gamut mapping results in Experiment 2 by our algorithm.
Calculation algorithm for spatial gamut mapping
- Preserves ratios at edges
- Uses relaxation labeling algorithm
- works well