A visual evaluation of the image reproduced by color decomposition based on spectral approximation for multiprimary display

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Introduction

◆ Concerning the advantage of MPD
  – Reducing the color mismatch caused by the variation of CMF
  – Spectrum decomposition methods
    • Considering CMF data
    • Considering original image spectrum
      → Murakami’s algorithm
  → Visual evaluation using actual image
  → Novel algorithm that reducing the cost of computation
Decomposition method based on spectral approximation

◆ Constraint of tristimulus match

\[ X_s = X P \alpha \]

\[ 0 \leq \alpha_i \leq 1, \quad i = 1,2,...,N \]

where \( s \) : target spectrum
\( P : n \times N \) primary matrix
\( \alpha : \) scalar value set for primary description

\[ \alpha = ( XP )^{-1} X_s \]

− Conventional methods determine the selection rule based on continuity and smoothness of display signals
◆ Color mismatch \( E_{XYZ}(\Delta X) \)

\[
E_{XYZ}(\Delta X) = \left\| (X + \Delta X)(s - P\alpha) \right\|
\]

\[
= \left\| X(s - P\alpha) + \Delta X(s - P\alpha) \right\|
\]

\[
= \left\| \Delta X(s - P\alpha) \right\|
\]

\[
\leq \left\| \Delta X \right\| \left\| (s - P\alpha) \right\|
\]

– The solution which minimizes the objective function

\[
E(\alpha) = \left\| s - P\alpha \right\|^2
\]
A novel algorithm

- Obtaining more precise results with less computational cost
- Lagrange function

\[
F(\alpha, \lambda) = \|s - P\alpha\|^2 + \lambda^t (XP\alpha - Xs)
\]

\[
\frac{DF}{D\alpha} = -2P^ts + 2P^tP\alpha + (XP)^t\lambda = 0
\]

\[
\begin{pmatrix}
2P^ts \\
Xs
\end{pmatrix} = \begin{pmatrix}
2P^tP & (XP)^t \\
XP & 0
\end{pmatrix} \begin{pmatrix}
\alpha \\
\lambda
\end{pmatrix}
\]

\[
\begin{pmatrix}
\alpha \\
\lambda
\end{pmatrix} = \left(2P^tP \quad (XP)^t\right)^{-1} \begin{pmatrix}
2P^ts \\
Xs
\end{pmatrix}
\]
Optimal solution

\[
\left( \alpha \right) = \left( \begin{array}{cc}
2P^t P & (XP)^t \\
XP & 0
\end{array} \right)^{-1} \left( \begin{array}{c}
2P^t s \\
Xs
\end{array} \right)
\]

– If solution satisfies constraint \( 0 \leq \alpha_i \leq 1, \quad i = 1, 2, \ldots, N \)

⇒ Optimal solution

– Else scalar values \( \alpha_i \)

⇒ fixed to 0 or 1 and

Possible combination

\( C = \sum_{1}^{N} C_{1} 2^1 + \sum_{2}^{N} C_{2} 2^2 + \ldots + \sum_{N-3}^{N} C_{N-3} 2^{N-3} \)

\[
F (\alpha_1, \lambda_1) = \| s - P_0 \alpha_0 - P_1 \alpha_1 \|^2 + \lambda_1^t (XP_1 \alpha_1 + XP_0 \alpha_0 - Xs)
\]

\[
\left( \begin{array}{c}
\alpha_1 \\
\lambda_1
\end{array} \right) = \left( \begin{array}{cc}
2P_1^t P_1 & (XP_1)^t \\
XP_1 & 0
\end{array} \right)^{-1} \left( \begin{array}{c}
2P_1^t (s - P_0 \alpha_0) \\
X (s - P_0 \alpha_0)
\end{array} \right)
\]
Experiment

◆ Using actual image
  – Cloth with pastel colors
    • Light blue and cream yellow → many solutions for the same tristimulus values
  – Capturing image using MSC(16 channel)
  – Reproducing image using 6-primary display
 Experiment condition

Fig. 1. An example image for the visual experiment

Fig. 2. Spectral distribution of a six-primary display
Comparing with LI, MS, TPD

Closer to the real object in the sense of color accuracy including the background

Table 1. Number of selections for each method

<table>
<thead>
<tr>
<th>Compared methods</th>
<th>Number of selections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear interpolation / Spectral-approx.</td>
<td>8 / 32</td>
</tr>
<tr>
<td>Matrix switching / Spectral-approx.</td>
<td>3 / 40</td>
</tr>
<tr>
<td>Three-primary / Spectral-approx.</td>
<td>3 / 32</td>
</tr>
</tbody>
</table>
Discussion

- Sensitive to the color difference near white color
- Comparing the RMSE
- Reproduced spectra
  - Have many peaks and valleys

Designing a spectral distribution of a display

Figure 4. Comparison between a real spectrum and reproduced spectra
Conclusion

◆ Evaluation the spectral approximation method using actual image
  – Comparing with other decomposition methods
  – Accuracy of the spectral estimation
  – High-fidelity color image reproduction