Color Gamut Mapping Based on Image Fusion

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Aim of the proposed method

- Reproducing perceptually closest to the corresponding original image
  - Image dependent gamut mapping via image fusion
    - Quantifying the perceptual difference between images
      » Divide and conquer
    - Mapping fusing model
Introduction

◆ Color gamut
  – Reproducible set of colors in devices

◆ Classical gamut mapping algorithm
  – Pixel by pixel mapping
    • Ignoring the spatial color configuration
      – Eliminating the edge
        » Mapping two colors to the same in-gamut color
      – Color distortion
        » Mapping out of gamut colors to different colors
Spatial gamut mapping algorithm

– Frequency domain
  • Compressing lightness using low pass filter in frequency domain
  • Adding the high pass filtered image
    – Detail information
- Two level approach
  - Initial gamut mapping (clipping)
  - Adding difference to initial gamut mapped image
  - Clipping
- Multiscale spatial GMA
  - Decomposition of original image into different spatial frequency band
– Multiresolution GMA
  • Based on retinex theory
– New spatial GMA
  • Replacing Gaussian filter to bilateral filter
– Multilevel GMA
  • Reducing hue shift and halo artifact
Evaluation of gamut mapping

- Color difference in CIELAB color space
  - General evaluation method
  - Acceptable mapped image with small $E$
  - Suitable for blocks with unity color

$$E = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} \| t_0 - t \|$$

where $u_0$ represent the original image in CIELAB,
$M, N$ are the width and height of the image measured in number of pixels,
$u$ is the final gamut mapped image with the same size,
$t_0, t$ are pixel vectors in $u_0, u$,
and $\| \| \|$ is the 2-norm.
– Subjective evaluation
  • Matching appearance of the image rather than individual color in image
    – Judging the similarity between images
    – Image containing complex contents, rich texture and details

– Perceptual difference
  • Defining two difference to guide the gamut mapping
    – Perceptual color difference
    – Perceptual gradient difference
    – CSF of human visual system
• Perceptual color difference

\[ D^c = f \ast (u^c - u_0^c) \]

\[ E_D = \sum_{c \in \{L, A, B\}} \| D^c \| \]

where \( c \in \{L, A, B\} \), \( L, A, B \) are the three component of CIELAB space, \( \ast \) denotes convolution, and \( f \) is the CSF function.

• Perceptual gradient difference

\[ G^c = \nabla D^c = \nabla [f \ast (u^c - u_0^c)] \]

\[ E_G = \sum_{c \in \{L, A, B\}} \| G^c \| \]

where \( c \in \{L, A, B\} \), \( \nabla \) is the gradient operator.
– Perceptual measure for gamut mapping
  • Similarity between the original and gamut mapped image

\[ E_{HVS} = \alpha E_D + (1-\alpha)E_G \]

where \( \alpha \in [0,1] \) is the gradient operator.
Proposed gamut mapping algorithm

- Proposed method
  - Optimization of perceptual measure
    - Assuming that the target device is convex
    - Difficult to get a unique optimum solution
      \[
      u_{opt}^c = \arg \min_{u^c} \sum_{c \in \{L,A,B\}} \{\alpha E_D + (1 - \alpha) E_G\}
      \]
  - Divide and conquer strategy
    - Initial gamut mapping
    - Comparing mapped image with original image
      - Identifying the max gradient distortion
      - Gradient keep algorithm
Divide and conquer

– Lemma 1

• Minimum $E$ clipping algorithm yields minimum $E_D$
• Definition of minimum $E$ clipping algorithm

$$\hat{x} = \begin{cases} \arg \min_x \|x - x'\| & x \in D \\ x & x \in J \end{cases}$$

This algorithm gives the minimum $E_D$
Lemma 2

- Image gamut based linear scale method yields minimum $E_\gamma$
  - Image gamut based linear scale method

$$\hat{x} = x + \lambda(x_0 - x) \in G$$

where $\lambda \in (0, 1)$ denote scale ratio, $x_0$ is the anchor point located at L axis.

$$\hat{x} - x = \lambda(x_0 - x)$$

$$\hat{x}_{i,j} - x_{i,j} = \lambda(x_0 - x_{i,j})$$

$$\hat{x}_{i+1,j} - x_{i+1,j} = \lambda(x_0 - x_{i+1,j})$$
• One order horizontal difference

\[
(\hat{x}_{i+1,j} - x_{i+1,j}) - (x_{i,j} - x_{i,j}) = \lambda (x_{i,j} - x_{i+1,j})
\]

• Two norm in both side

\[
\left\| (\hat{x}_{i+1,j} - x_{i+1,j}) - (x_{i,j} - x_{i,j}) \right\| = \left\| \lambda (x_{i,j} - x_{i+1,j}) \right\|
\]

– Minimum one order difference quantity

» Constant of \( \left\| (x_{i,j} - x_{i+1,j}) \right\| \)

\[
\lambda = \lambda_{\text{min}}
\]

This algorithm gives the minimum \( E_G \)
◆ Image fusion

– Merging the advantage of \( u_1 \) and \( u_2 \)
  
  • Initial gamut mapped image (\( u_1 \))
    
    – Maintaining most color fidelity
    
    – Color cloud
  
  • Image gamut based linear scale method (\( u_2 \))
    
    – Losing much color fidelity when applying \( u_1 \)

– Sharp edge image of binary image

\[
I_{\text{sharp}}(i, j) = \begin{cases} 
0, & I(i, j) \leq T \\
1, & I(i, j) > T 
\end{cases}
\]
– Transforming perceptual difference to binary

• Sharp edge image ($I_{\text{sharp}}$)
• Segmenting image ($u_o$) to yield the region with large color distortion ($u_{\text{seg}}$)
• Fusing final image ($u_f$)
  – Achieving via a fusion model

\[
u_f(i, j) = \begin{cases} 
  u_1(i, j), & (i, j) \notin u_{\text{seg}} \\
  u_2(i, j), & (i, j) \in u_{\text{seg}}
\end{cases}, i = 1, \ldots, M, j = 1, \ldots, N
\]
- Flowchart of the proposed algorithm

- Minimum ΔE clipping
- Calculate $G_1$
- Calculate $I_{\text{sharp}}$
- Image segmentation
- Image fusion
- Image gamut based linear scale
Experimental results

- Mapping image to printer
  - 512x512 business picture

(a) Original image
(b) Image gamut
(c) Printer gamut

Fig. 2. Image and device gamut
Fig. 3. Image and device gamut
– Results of gamut mapping
  • Color difference
  • Perceptual difference

Table 1. Evaluation index of the three GMAs

<table>
<thead>
<tr>
<th>Name of GMAs</th>
<th>$E$</th>
<th>$E_{HVS}$</th>
</tr>
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<tbody>
<tr>
<td>minimum ΔE clipping</td>
<td>2.7805</td>
<td>5.2848</td>
</tr>
<tr>
<td>image gamut based linear scale</td>
<td>10.999</td>
<td>7.5603</td>
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<tr>
<td>Proposed</td>
<td>4.015</td>
<td>4.8369</td>
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</tbody>
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Summary

◆ Proposed method
  – Using human visual based image evaluation model
    • Divide and conquer scheme and mapping fusion model
  – Segment into two kinds of regions
    • Little edge distortion
      – Clipping mapping
    • Other region
      – Linear scale mapping