High-Dynamic Range Imaging Techniques Based on Both Color-Separation Algorithms Used in Conventional Graphic Arts and the Human Visual Perception Modeling

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Abstract

◆ Proposed method
  – Deriving illuminant-independent type of HDR imaging modules
    • Reconstruct of every color concerned in high-dynamic-range of original images
    • Tone-mapping module
      – Derived based on a multiscale representation of the human visual system
      – Using equations similar to a photoreceptor adaptation equation
    • Adaptive bilateral type of gamut mapping algorithm
      – Incorporated with or without adaptive Un-sharp Masking (USM)
        » Carry out the optimization of HDR image rendering
**Introduction**

- **High dynamic range (HDR)**
  - Dynamic range
    - Ratio of the highest to the lowest luminance or signal level
  - Real world dynamic range
    - Approximately fourteen orders of magnitude
  - Performance of digital image capture and display devices
    - Match or even exceed performance of film
      - Accuracy
      - Resolution
    - Sufferance of limited dynamic range
Computational Framework of Model

◆ Tone reproduction techniques
  – Global tone mapping operators
    • Simple
    • Preservation of intensity orders of original scenes
      – Avoiding halo artifacts
  – Previous global tone mapping operators
    • Tumblin and Rushmeier
      – Match perceived brightness of displayed image with brightness of scene
    • Ward
      – Match perceived contrast between displayed image and scene
Fig. 1. The specific computational procedures used to implement each step of the model.
– Tone Mapping Algorithm

• Preservation of details and local contrast
• Consider pixel neighborhood information in mapping processing for each individual pixel

Fig. 2. Computation procedures of the multiscale model of adaptation and spatial vision for realistic tone mapping.
– Device Characterization and Gamut Mapping
  • Novel fast global histogram adjustment
    – Utilization of full dynamic range of display
    – Reproduction of global contrast
    – Insufficient preservation of local contrast and details

Fig. 3. Gamut mapping using a multiple-conversing-points approach.
Fig. 4. Proposed framework of the adaptive gamut mapping algorithm applied...
Applying the model and evaluations

- HDR Tone Mapping Algorithm
  - Increase of contrast and brightness
    - Low luminance value
  - Compression of contrast and brightness
    - High luminance value

\[
D(I) = (D_{\text{max}} - D_{\text{min}}) \times \frac{\log(I + \tau) - \log(I_{\text{min}} + \tau)}{\log(I_{\text{max}} + \tau) - \log(I_{\text{min}} + \tau)} + D_{\text{min}} \quad (1)
\]

where \( I_{\text{min}} \) and \( I_{\text{max}} \) are the minimum and maximum luminance of the scene, \( D_{\text{max}} \) and \( D_{\text{min}} \) are the maximum and minimum display levels of the visualization devices, and \( \tau \) controls the overall brightness of the mapped image.
– Result of different values of $\tau$

Fig. 5. Application of the model using a linear (a), an exponential (b and c) and a logarithmic mapping (d).
Device Characterization and Gamut Mapping

- Estimate of parameter
  - Log-average luminance of scene
    - Mapping specific point in display dynamic range depending on scene brightness
  - Procedure
    - Calculate log-average luminance \( I_{\text{ave}} \) of scene
      \[
      I_{\text{ave}} = \exp \left[ \frac{1}{N} \sum_{x,y} \log (\varepsilon + I(x,y)) \right] \tag{2}
      \]

where \( N \) is the total pixel number in the image, \( I(x,y) \) is the luminance value whose minimal can be 0 for pure black point, and a small value \( \varepsilon \) is used to avoid the singularity that occurs with 0 values in these cases when taking logarithm operation.
– Calculate key value of image on scale between 0 and 1

\[ k = A \times B^{(2 \log I_{ave} - \log I_{min} - \log I_{max})/(\log I_{max} - \log I_{min})} \]  

(3)

where constants A and B are empirically set to 0.4 and 2, and thus k range form 0.2 to 0.8.

– Decide offset \( \tau \)

  » Use of numerical calculation

\[ k = \frac{\log(I_{ave} + \tau) - \log(I_{min} + \tau)}{\log(I_{max} + \tau) - \log(I_{min} + \tau)} \]  

(4)
- Division of range of D(I)

<table>
<thead>
<tr>
<th>Test Images</th>
<th>Test Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Scales of RGB CMY</td>
<td>(5) Wools</td>
</tr>
<tr>
<td>(2) Ski</td>
<td>(6) Fruits</td>
</tr>
<tr>
<td>(3) Scene of River</td>
<td>(7) Bride Clothes</td>
</tr>
<tr>
<td>(4) Color Patches and Bars</td>
<td>(8) Silvers and Bottles</td>
</tr>
</tbody>
</table>

**Fig. 6.** Images used in the test of gamut mapping algorithm.
– Histogram adjustment based linear to equalized quantizer (HALEQ)

\[ le_n = l_n + \beta (e_n - l_n) \]  \hspace{1cm} (5)

where \( 0 \leq \beta \leq 1 \) is a controlling parameter.

**Table 1.** Seven gamut mapping (GM) algorithms tested.

<table>
<thead>
<tr>
<th>Model</th>
<th>GM1</th>
<th>GM 2</th>
<th>GM 3</th>
<th>GM 4</th>
<th>GM 5</th>
<th>GM 6</th>
<th>GM 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM method</td>
<td>Clipping</td>
<td>Linear Compression</td>
<td>S-Shape</td>
<td>Adjusted Clipping</td>
<td>Adjusted Linear Compression</td>
<td>Adjusted Clipping</td>
<td>Adjusted Linear Compression</td>
</tr>
<tr>
<td>USM</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
– Mapping results and mapping curves
  • Existence of very few very bright pixels
    – Correspond to area of lamps

**Fig. 7.** GMAs performance evaluated using the paired comparison method.
Adaptive local histogram adjustment (ALHA)

- Characteristic of HALEQ
  - Effective utilization of dynamic range of display
- Segment image into small regions
- Applying HALEQ in each local area
  - Full display dynamic range
◆ HALEQ in local regions
  – Logarithmic mapping (Eq.(1))
  – Determination of local regions
  • Division of image into non-overlapping regular rectangular blocks

**Fig. 6.** Left: divide the image into blocks and then apply HALEQ technique developed in Section 3 to each individual block.
– Output integer display level $d(x, y)$

$$d(x, y) = HALEQ_n[D(x, y)] \quad (x, y) \in n$$  \hspace{1cm} (6)

**Fig. 7.** The mapping functions and histograms for two different local areas A and B of an example image (The right image of Fig. 9).
Normalized histograms of area A after applying different approaches to D(I)

- Top: histogram from the linear quantization.
- Middle: histogram from the original HALEQ.
- Bottom: histogram from local HALEQ.

**Fig. 8.** Normalized histograms of area A after different approaches are applied to D(I) output by Eq. (1). Top: the histogram from the linear quantization. Middle: histogram from the original HALEQ. Bottom: histogram from local HALEQ.
– Mapping results from local HALEQ method
  • More details and local contrast in either dark or bright regions
  • Boundary artifacts

Fig. 9. Mapping results from local HALEQ. Memorial radiance map courtesy of Paul Debevec, University of California at Berkeley; Clock building radiance map courtesy of Greg Ward.
– Solution to boundary artifact

- Weighted average of results from tone mapping function

\[
d(x, y) = \sum_{n=1}^{n=K} \text{HALEQ}_n \left[ D(x, y) \right] \cdot w_d(n) / \sum_{n=1}^{n=K} w_d(n)
\]  
(7)

where distance weighting function \( w_d \) is calculated as

\[
w_d(n) = e^{-\left( d_n / \sigma_d \right)}
\]
(8)

where \( d_n \) is the Euclidean distance between the current pixel position and the centers of each of the blocks, \( \sigma_d \) controls the smoothness of the image.

**Fig. 6.** Right: distance weighting function is introduced to eliminate the boundary artifacts. For easy illustration, only 9 blocks are used in this figure.
Conclusion and future work

◆ Proposed method
  – Novel histogram adjustment method
    • Global tone mapping operator HALEQ
      – Fast and well reproduce global contrast
      – Lack of local contrast
    • Local tone mapping operator ALHA
      – Adapt global HALEQ to local implementation
      – Applying HALEQ directly into local areas
      – High quality results with very faster computation speed and fewer parameter adjustments

◆ Future work
  – Achieve real-time computation for local tone mapping algorithm