Tone Reproduction: A Perspective from Luminance-Driven Perceptual Grouping

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Abstract

◆ Tone reproduction
  – Compression of HDR luminance for display

◆ Proposal
  – Luminance-driven perceptual grouping process
    • Sparse representation of HDR luminance
    • Approximation of local properties of luminance
  – Piecewise tone mapping
    • Monotonize of the relative brightness
Introduction

◆ Related work
  – Global mapping (uniform mapping)
    • Good efficiency
    • Smoothing
  – Local mapping (nonuniform mapping)
    • Properties
      – Improvement of visual fidelity
      – Usage of local adaptation to match human perception
      – Overemphasis
        » Halo effect
• Center-surround manner
  – visual cells
  – Calculation of the average intensity of a proper circular region to adjust a mapping function

• Decomposing a radiance map
  – Illumination layer
    » Luminance information
    » Wider dynamic range
    » Compression for tone reproduction
  – Reflectance layer
    » Textures
    » Low dynamic range

– Segmentation view point

• Method
  – Segmentation of an image into zones of similar values
  – Computation of the average intensity of each zone
  – Usage of the average value to use nonuniform tone mapping function
Our approach

– Grouping process
  • Sparse representation for HDR images

– Tone mapping
  • Estimation of local adaptation luminance
    – Preservation of local details and global perceptual impression
  • Piecewise tone mapping
$L$ (Luminance in a 32bit RGB HDR image)

Luminance map

Sparse representation

$\log(L)$

Adaptive block partition
Perceptual grouping

Region-wise tone mapping

$L'$ (Displayable luminance)

Application of the ratio $L'/L$ to HDR RGB channel
A sparse representation for HDR images

◆ Procedure
  – Obtainment of the luminance map from HDR
    \[ L(x, y) = 0.2126R(x, y) + 0.7152G(x, y) + 0.0722B(x, y) \]
  – Sparse representation
    • Decomposition of HDR image into a perceptual grouping
    • Two steps
      – Adaptive block partition
      – Perceptual grouping
  – Compression with region-wise
◆ Adaptive block partition

– Usage of the logarithmic domain
  • Perception of intensity ratio for the HVS sense
    \[ \tilde{L}(x, y) = \log L(x, y) \]

– Partition of the image with blocks
  • Prevention of time consuming and noise sensitivity
  • Usage of two size blocks
    – Smaller blocks for edge area \((b_s \times b_s = 2 \times 2)\)
    – Bigger blocks for flat area \((b_l \times b_l = 8 \times 8)\)
  • Usage of Canny edge detector for finding edges

Fig. 1. Log luminance and adaptive block partitions.
Perceptual Grouping

- Perceptual distance
  
  • Evaluation of the perceptual similarity
  
  • Usage of earth mover’s distance (EMD)
    - Conversion of the luminance value in the blocks into signature
    - Method
      
      » Division of the dynamic range of a block into three bins
      » Calculation of the mean $s_i$ and pixel number $h_i$ in each bin
      » Calculation of weights, $w_i = h_i / \sum_j h_j$
      » Presentation of the signature $p_i$ as the signature of region $\mathcal{R}_k$

      \[ p = \{(s_1, w_1), (s_2, w_2), (s_3, w_3)\} \]

      
      - Definition of perceptual distance

      \[ D(\mathcal{R}_1, \mathcal{R}_2) = \text{EMD}(p_1, p_2) \]  \hspace{1cm} (1)
Luminance-driven grouping

- **Brightest-block-first rule**
  - Comparison of the $s_i$ for each block to identify the brightest block

- **Grouping**
  - Mark all blocks as *unvisited*
  - Set the brightest block as $B_i$
  - Grow the region from $R_k$ where $k$ is the number of region
    - Smaller EMD than $\delta$ ($0.5 \leq \delta < 1.0$)
  - Stop growing when EMD is in the threshold, $\theta$ ($1.0 \leq \theta < 1.5$)

Fig. 1. The parse representation of 8 regions and the result from our method.
Region-based tone mapping

◆ Local adaptation luminance for tone mapping
  – Local adaptation effect
    • Average log-luminance of a suitable neighborhood for each pixel
  – Bilateral filtering method
    • Calculation of the local adaptation log-luminance at \((x,y)\) in region \(\mathcal{R}_k\)
    • Computation of bilateral effects from difference regions
• Equation for the local adaptation log-luminance

\[
\tilde{V}(x, y) = \frac{1}{\tilde{Z}_{x,y}} \left\{ \sum_{(i,j) \in R_k} \tilde{L}(i, j)G_{x,y}(i, j)K_{x,y}(i, j) \right\} + \sum_{(i,j) \notin R_k} \tilde{L}(i, j)G_{x,y}(i, j)K'_{x,y}(i, j) \}
\]

(2)

Where

\[ G_{x,y}(i, j) = \exp\left\{ -((i - x)^2 + (j - y)^2) / 2\sigma_s^2 \right\} \]

\[ K_{x,y}(i, j) = \exp\left\{ -(\tilde{L}(i, j) - \tilde{L}(x, y))^2 / 2\sigma_r^2 \right\} \]

\[ K'_{x,y}(i, j) = \exp\left\{ -(\tilde{L}(i, j) - \tilde{L}(x, y))^2 / 2\sigma_r' \right\} \]

\[ \tilde{Z}_{x,y} = \sum_{(i,j) \in R_k} G_{x,y}(i, j)K_{x,y}(i, j) + \sum_{(i,j) \notin R_k} G_{x,y}(i, j)K'_{x,y}(i, j) \]

\[ \sigma_r \geq \sigma_r' \]

More expanded range in the same region

\[ \sigma_s \text{ is 4\% of image size, } \sigma_r = 0.4, \text{ and } \sigma_r' = 0.5 \times \sigma_r \]

• Local adaptation luminance

\[ V = \exp(\tilde{V}) \]
件wise tone mapping
– Review of Compression of the high luminance into displayable range
  • Global mapping with Smoothing effect
    – Good property at monotone for preventing halo effect
      \[ L' = \varphi(L) = \frac{L}{1 + L} \]
      Where \( 0 \leq L' \leq 1 \) is displayable range.
  • Local mapping for preserving details
    \[ H = \frac{L}{V} : \text{Detail layer} \]
    \[ V' = \varphi(V) : \text{Compression of local adaptation luminance} \]
    \[ L' = H \times V' = \left( \frac{L}{V} \right) \times \left( \frac{V}{1 + V} \right) = \frac{L}{1 + V} \]
    Where \( L' \) is displayable luminance.
– Piecewise tone mapping

• Design a local mapping, $\psi$

\[
\psi(L, V; \rho, \gamma) = \left( \frac{L}{V} \right)^\rho \varphi^\gamma(V) = \left( \frac{L}{V} \right)^\rho \left( \frac{V}{1+V} \right)^\gamma
\]  

(3)

Where $0 < \rho < 2$ and $0 < \gamma \leq 1$ are spatial-dependent parameters.

– $\gamma = 0.3$ at this experiments

• Globally reshape

– Mapping the luminance range into $[0, 1]$

\[
\tilde{\varphi}^\gamma = \alpha \varphi^\gamma + \beta
\]

Where $\alpha$ is the scaling parameter and $\beta$ is the shifting parameters.

\[
\begin{bmatrix}
\tilde{\varphi}^\gamma(L_{\text{max}}) \\
\tilde{\varphi}^\gamma(L_{\text{min}})
\end{bmatrix}
\begin{bmatrix}
1 \\
1
\end{bmatrix}
\begin{bmatrix}
\alpha \\
\beta
\end{bmatrix}
= 
\begin{bmatrix}
1 \\
0
\end{bmatrix}
\]  

(4)
• Estimate $\rho$ by kernel smoothing
  – Construction of $D_k$ within $\mathcal{R}_k$
    » Largest grid with $\epsilon \times \epsilon$ resolution from the region boundary $\partial \mathcal{R}_k$
  – Assignment of some preliminary $\rho_n$ value to each pixel $n \in D_k$
    $$\rho_n = \begin{cases} 
    \gamma, & \text{if } \log(L_n/V_n) \leq -1, \\
    (\gamma + \rho_{\text{max}})/2, & \text{if } \log(L_n/V_n) \geq 1, \\
    \rho_{\text{max}}, & \text{otherwise.}
    \end{cases}$$

  » Overemphasis with a larger $\rho_n$ at very different values between $L_n$ and $V_n$
  » $\rho_n = \gamma$ on $\partial \mathcal{R}_k$ for all pixels
  – Interpolation of the $\rho_n$ value between $D_k$ and $\partial \mathcal{R}_k$
  – Kernel smoothing after assignment on the whole image
- $\rho_n$ value after kernel smoothing in fig 3.
  $\Rightarrow \rho_{\text{max}} = 1.8$ and $\epsilon = 4$ in the experiments

Fig. 3. The $\rho$ value after kernel smoothing.
• Monotonization of local tone mappings
  – Estimation of $\alpha_k$ and $\beta_k$
    » Elevation of $\psi$ into $\tilde{\psi} = \alpha_k \psi + \beta_k$
    » Compression of the luminance with both local and global factor
  – Method
    » Sampling N pixels from $\partial R_k$ according to the sorted $|\log(L_n / V_n)|$ values in ascending order
    » Condition for calculating $\alpha_k$ and $\beta_k$

\[
\begin{bmatrix}
\psi_1 & \cdots & \psi_N \\
1 & \cdots & 1
\end{bmatrix}^T
\begin{bmatrix}
\alpha_k \\
\beta_k
\end{bmatrix} =
\begin{bmatrix}
\tilde{\phi}_1^\gamma & \cdots & \tilde{\phi}_N^\gamma
\end{bmatrix}^T
\]
– Final displayable luminance value, $L'(x,y)$

$$\tilde{\psi}(L, V; \rho, \gamma) = \alpha_k \psi(L, V; \rho, \gamma) + \beta_k$$

• Emphasis of the local details of each region without breaking the global visual consistency

◆ Whole procedure

Fig. 4. The steps of our tone reproduction method.
Experiments and Discussions

- Radiance map with multi exposure values
  - 250,000:1 dynamic range

*Fig. 5.* Radiance map on a fixed displayable range.
Comparison with other result

- Better at the brighter area
- Better contrasts and more details
  - Usage of $\rho$ and $\gamma$

(a) Bilateral filtering  (b) Photographic tone reproduction  (c) Our method  (d) Gradient domain

Fig. 2. Result for comparison.
Result images
  – Overall impression luminance
  – Details and local high contrast

Fig. 6. HDR tone-reproduction results
– Comparison

• Brighter luminance at the sun between (a) and (b)
• Reduction of halo effect in (d) at skyline and near the shadow
• Lower contrast along boundaries

Fig. 7. Result for comparison.
Conclusion

◆ Investigation of tone reproduction problems
  – Local adaptation luminance for details
  – Region-wise compression for the overall impression

◆ Proposal
  – Luminance-driven perceptual grouping based on EMD perceptual distance
  – Improvement of tone mapping functions