Optimizing Gamut Mapping: Lightness and Hue Adjustments

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Flowchart

Introduction of gamut mapping

Chroma compression with constant lightness

Chroma compression with modified lightness

Issues of gamut mapping

Mapping towards a focal point

Relative lightness Change mapping
Abstract

- Issues of gamut mapping
  - The mapping space
  - The coordinate system within the space
  - The gamut boundary description
- Investigation of several chroma compression algorithms with constant and modified lightness and hue
- Evaluation of mapping type and mapping direction
Proposed Gamut mapping

- Mapping colors towards a focal point
- Relative Lightness Change (RLC) technique
Introduction

◆ Gamut mapping
  – An important step in color image reproduction
  – Technical limitation
    • Variation between color rending processes
    • Differences in viewing condition
    • A perfect match of a reproduced image to the original

◆ Evaluation’s of color images
  – Psychophysical experiments

◆ Proposed method
  – Preserve higher chroma
    • Based on modification of lightness and hue
Parameters of Gamut Mapping

- Direction versus type of mapping
  - Two basic parameters
    - The direction of mapping
      - Lightness/brightness information
    - The type of mapping
      - Variation of Clipping and linear compression
  - The optimum mapping type depends on the mapping direction
  - The optimum direction mapping depends on the specified type of mapping
  - Extend to include the modification of the hue angle
◆ Color spaces and coordinates system
  – Mapping space
    • Based on human perception
    • Correlates of perceived lightness, chroma and hue
    • The coordinate system to choose within the color space
      – Lightness constant → Cylindrical coordinates
      – Centroid mapping → Spherical coordinates
◆ Gamut boundary description
  – Calculation of image gamut
    • Scanning all the image gamut
    • Finding the maximum chroma for a given lightness-hue pair
  – The image gamut boundary
    • Smoothing gamut boundary
    • Depending on the direction
  – Gamut boundary description
    • Proposed by Morovic
    • Using segment
    • Very compact and reasonably accurate
– Gamut boundary

Fig. 1. Maximum operator for the smoothing of image gamuts.
• Some drawbacks
  – Uncorrelates in terms of perceptual attributes
  – Very sophisticated technique in cross sectioning of a certain mapping direction

– The latest achievement of image capture
  • Multispectral imaging
  • Multispectral printing
◆ Chroma compression with constant lightness
  – Constant of CLELAB lightness and hue angle
  – Type of mapping: Linear compression and clipping
  – Three ensembles
    • Class 1: Representation of the piecewise linear compression functions of Gentile
    • Class 2: Compression of the remainder of the colors to the remaining region above the threshold
    • Class 3: Approximation to class 1, but rounded edge
  – Clipping better than linear compression
– The degree of clipping parameter

Fig. 2. Ensemble of mapping type for mapping along the cylindrical/spherical radius for a maximum reproduction radius of 0.6. The degree of soft clipping is dependent on parameter $\lambda$. 
Chroma compression with modified lightness
  – Using the reproduced chroma lower than the original chroma
  – Centroid mapping
    • Mapping towards a fixed focal point on the lightness axis
    • Disadvantage
      – Bright area in image → more darken
      – Dark area in image → more lighten
  – Hybrid mapping
    • Centroid → in the upper half
    • Constant lightness → in the lower half
– Two step technique
  • Certain amount of chroma compression : constant lightness
  • Centroid mapping

◆ Lightness change would produce the most acceptable results
Gamut mapping method

- Proposed gamut mapping method
  - Mapping colors towards a focal point
  - Relative Lightness Change (RLC) technique
  - The goal of gamut mapping
    - To conserve as much of the original chroma
    - A major concerned of the degree of clipping
  - The mapping type
    - The monotonically increasing function
Mapping towards a focal point

- The mapping method
  - To clip all out-of-gamut colors towards a focal point on the lightness axis
  - Mapping direction → To lightness modification

- Our ideal
  - To focal point of mapping towards negative chroma
  - To focal point
    - Depending on the hue angle and locating at the lightness of the cups
Fig. 3. To achieve a mapping direction between mapping towards the cups point and mapping with constant lightness, the focal point is moved towards negative chroma.
– The equal lightness

Fig. 4. Contour lines of equal lightness after clipping out-of-gamut colors towards the focal point at $C^* = 0$ and $L^* = L_{cusp}^*$. 
Relative lightness change mapping

- Mapping in varying directions
  - Based on lightness changes
  - Mapping colors with curved lines
  - Relative to the L-distance from cusp
  - Relative to the C-distance from the gamut boundary

- Algorithm

\[
\text{If } (C^* < \lambda \hat{C}_{\text{out}} (L^*, h^*)) \text{ or } (\hat{C}_{\text{in}} (L^*, h^*) < \hat{C}_{\text{out}} (L^*, h^*)) \text{ ; Do Nothing,}
\]

\[
\hat{C}_{\text{in}} (L^*, h^*) : \text{boundaries of the image gamut}
\]

\[
\hat{C}_{\text{out}} (L^*, h^*) : \text{boundaries of the reproduction gamut}
\]

\[
\lambda : \text{degree of soft clipping}
\]
Otherwise

\[ \Delta L^* = \frac{\alpha}{100} \frac{(L_{CUSP}^*(h^*) - L^*)(C^* - \lambda \hat{C}_{out}(L^*, h^*))}{C_{ref} - \lambda \hat{C}_{out}(L^*, h^*)} \]

\[ L_{mod}^* = L^* + \Delta L^* \]

\[ C_{mod}^* = \lambda \hat{C}_{out}(L_{mod}^*, h^*) + (1 - \lambda) \hat{C}_{out}(L_{mod}^*, h^*) \cdot \frac{C^* - \lambda \hat{C}_{out}(L_{mod}^*, h^*)}{\hat{C}_{in}(L^*, h^*) - \lambda \hat{C}_{out}(L_{mod}^*, h^*)} \]}
- RLC mapping method parameters

\[ L_{cusp}^* (h^*) : \text{Lightness of the cusp at a given hue angle} \]

\[ C_{ref} : \text{Parameter the curvature of the mapping direction} \]

\[ C_{ref} = \sqrt{2} \times 128 : \text{experiment} \]

\[ \alpha : \text{Degree of lightness change} \]

\[ \alpha = 0 : \text{no change} \]

\[ \alpha = 100\% : \text{maximum lightness change} \]

\[ \lambda : \text{Degree of soft clipping} \]

\[ \lambda = 0 : \text{linearcomp ression} \]

\[ \lambda = 100\% : \text{clipping} \]
– RLC method

Fig. 5. Contour lines of equal lightness after clipping out-of-gamut colors with relative lightness change and $\alpha = 100\%$. 
Experiments

- Paired comparison
  - Viewing same media: Barco calibrated monitor
    - Monitor, dye diffusion thermal transfer printer
  - Psychophysical experiment
    - Dark surround
    - Lightness ranges: 0-100
    - Positions on the Screen are random
    - Test time: 30s/image pair
  - Image dependent algorithm
– The psychophysical experiments image

Fig. 6. The images used in the psychophysical experiment.
– A number of out-of-gamut and distance

Fig. 7. The colors of the “child” image together with the maximum printer chroma (50%-scaled) in the $a^*b^*$ projection.
Experiment I

- Investigated the optimum mapping direction for a given mapping type
- Mapping type → Clipping
- Testing direction
  - Mapping with constant lightness
  - Mapping towards a focal point at the lightness of the cusp
  - Relative lightness change
– Result of experiment I

Fig. 8. Rating of the eight tested methods of experiment I on a psychophysical scale averaged over eight observers and all image. Algorithms are dL0, RLC25, RLC50, RLC100, FO0, F-20, F-50, F-100, all with $\lambda = 1$ (clipping).
Experiment II

- To optimize mapping type for a given mapping direction
- RLC50 and F0 mapping direction
- Mapping type: Linear compression to clipping
- Result of experiment II

Fig. 9. Rating of the eight tested methods of experiment II on a psychophysical scale for the accuracy of four test images. Algorithms are RLC50\(\lambda_0\), RLC50\(\lambda_{1/3}\), RLC50\(\lambda_{2/3}\), RLC50\(\lambda_1\), F0\(\lambda_0\), F0\(\lambda_{1/3}\), F0\(\lambda_{2/3}\), F0\(\lambda_1\), where “\(\lambda_{2/3}\)” means \(\lambda=2/3\). ‘la’ in the graphic means ‘\(\lambda\)’.
Example images (I, II)-girl

Fig.9  Original images

Fig.10  RLC50λ1

Fig.11  F0λ0

Fig.12  F0λ1
Example images (I, II)-creek

Fig. 13  Original images
Fig. 14  RLC50λ1
Fig. 15  F0λ0
Fig. 16  F0λ1
Experiment III

- The usefulness of hue modifications in order to preserve higher chroma
- Modified up to a certain limit $\pm 10^\circ$
- Change $\pm 1^\circ$ at each steps
– Hue modification

Fig. 17. Hue modifications provide a means to retain higher chroma in reproduced images.
Hue modification
  – Improve the appearance of reproduced images

Artifacts
  – Applied to independently for each pixel: Color seams
  – Ex) yellow hue
    – Chroma gain is high for high lightness
    – Chroma gain is low for low lightness
  – Same hue: Same modification vector
  – Result
    – Perfect result is not acquired
Conclusions

◆ Gamut mapping algorithms
  – Different mapping types and mapping directions
  – Focal point mapping and RLC method
    • Moderate adjustment of lightness and hue
    • Optimum mapping direction : RLC50

◆ Future work
  – Verified under different conditions
    • Mapping from monitor to real printer
    • Further test images : more complex scenes