

Image Quality Measures for Evaluating Gamut Mapping

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Abstract

◆ Objective

- Comparison of different image quality measures for gamut mapping algorithms
- Validation of those with psycho-visual data from four gamut mapping algorithms
- New image quality based on color and local contrast

Introduction

- ◆ Importance in gamut mapping algorithm
 - Needs accurate evaluation of psycho-visual performance
 - Usually uses Thurstone's Law of Comparative Judgement
 - Needs image quality measure
 - Quality for preservation of lightness/color and spatial detail
- ◆ Good image quality measure
 - Evaluates gamut mapping without psycho-visual study
 - Psycho-visual study
 - Most reliable
 - Time consuming

◆ Challenge

- Finds a measure correlated well with observer's preference

◆ Main topic

- Comparison of the performance of image quality measures with data driven quality measures from psycho-visual test

Image quality measures

◆ Review

- Two images; X and Y
- Pixels for each image; $x_{ij} \in X$ and $y_{ij} \in Y$
- Lightness as L in CIELAB

◆ Structural similarity index (SSIM)

- Uses only L in CIELAB
- Let a patch as $P_X \subset X$ and $P_Y \subset Y$ with $k \times k$ (local measure)
- Compute the average

$$\bar{P}_X = \frac{1}{k^2} \sum_{x \in P_X} x, \quad \bar{P}_Y = \frac{1}{k^2} \sum_{y \in P_Y} y, \quad (1)$$

- Compute the standard deviation

$$\begin{aligned}\sigma_{P_X}^2 &= \frac{1}{k^2 - 1} \sum_{x \in P_X} (x - \bar{P}_X)^2, \\ \sigma_{P_Y}^2 &= \frac{1}{k^2 - 1} \sum_{y \in P_Y} (y - \bar{P}_Y)^2, \text{ and} \\ \sigma_{P_X P_Y} &= \frac{1}{k^2 - 1} \sum_{i=1}^{k^2} (x_i - \bar{P}_X)(y_i - \bar{P}_Y)\end{aligned}\tag{2}$$

- Compute SSIM which can be used as Q_{SSIM}

$$\text{SSIM}(P_X, P_Y) = \frac{(2\bar{P}_X \bar{P}_Y + c_1)(2\sigma_{P_X P_Y} + c_2)}{(\bar{P}_X^2 + \bar{P}_Y^2 + c_1)(\sigma_{P_X}^2 + \sigma_{P_Y}^2 + c_2)}\tag{3}$$

- Range as [-1, 1]

◆ Laplacian mean square error (LMSE)

- Local measure

$$L(x_{ij}) = x_{(i+1)j} + x_{(i-1)j} + x_{i(j+1)} + x_{i(j-1)} - 4x_{ij} \quad (4)$$

$$L(y_{ij}) = y_{(i+1)j} + y_{(i-1)j} + y_{i(j+1)} + y_{i(j-1)} - 4y_{ij}$$

- Compute Q_{LMSE} as image quality measure

$$Q_{\text{MSE}}(X, Y) = \frac{1}{nm} \sum_{i=1}^n \sum_{j=1}^m (x_{ij} - y_{ij})^2 \quad (5)$$

◆ Mean square error (MSE)

- Squared pointwise difference
- Image quality measure as Q_{MSE}

$$Q_{\text{MSE}}(X, Y) = \frac{1}{nm} \sum_{i=1}^n \sum_{j=1}^m (x_{ij} - y_{ij})^2 \quad (6)$$

◆ Discrete wavelet transform (DWT)

- Use luminance layer
- Let M_X^f be the magnitudes of the DWT coefficients for X and frequency band f and M_Y^f
- Calculates the difference

$$d_i^f(X, Y) = \left| M_{X_i}^f - M_{Y_i}^f \right|, \quad i = 1, \dots, \left| M_X^f \right| = \left| M_Y^f \right| \quad (7)$$

- Calculates $\sigma_f(X, Y)$ as standard deviation of $d_i^f(X, Y)$
- Defines Q_{DWT} as mean of $\sigma_f(X, Y)$

A new quality measure

- ◆ Important factor for gamut mapping
 - Color preservation and contrast (detail) preservation
- ◆ The measure $Q_{\Delta E}$
 - Euclidean distance in CIELAB color space between X and Y

$$\Delta E(x, y) = \sqrt{((L_x - L_y)^2 + (a_x - a_y)^2 + (b_x - b_y)^2)} \quad (8)$$

- Image quality metric $Q_{\Delta E}$ as average ΔE

$$Q_{\Delta E}(X, Y) = \frac{1}{nm} \sum_{i=1}^n \sum_{j=1}^m \Delta E(x_{ij}, y_{ij}) \quad (9)$$

- ◆ The measure $Q_{\Delta LC}$
 - Local contrast measure
 - Let a patch $P_X \subset X$ with $k \times k$
 - Calculates Michelson contrast

$$LC(P_X) = \frac{x_{max} - x_{min}}{x_{max} + x_{min}} \quad (10)$$

Where, x is an luminosity coordinate in XYZ color space and $x \in P_X$

- Image quality metric $Q_{\Delta LC}$ as the average of ΔLC

$$\Delta LC(P_X, P_Y) = |LC(P_X) - LC(P_Y)| \quad (11)$$

Thurstone's method and conjoint analysis

◆ Traditional methods

– Thurstone's law of comparative judgement

- Pairwise comparison
- Assign a single value to a mapping algorithm

– Conjoint analysis

- Extension of Thurstone's method
- Assign a value to all the parameters in algorithm and sum up those scale values

◆ Uses as reference for image quality measure

- ◆ Individualized Thurstone's method and individualized conjoint analysis

- To improve the consistency of results, individualize the evaluation for each image

Validating the quality measure

- ◆ Validation of the suitability of an image quality metric for gamut mapping
 - How well align with observer ratings obtained in psycho-visual tests
 - Use cross validation
- ◆ Hit rate
 - Percentage of correctly predicted observer choices
 - Let C be the set of non-tied observer choices
 - Predict the choice with the higher value for this measure on the elements in C
 - Let $S \subseteq C$ be the subset of correctly predicted choices
 - Hit rate

$$HR = \frac{|S|}{|C|}$$

$$\frac{\sum \text{Sales Won}}{\sum \text{Sales Won} + \sum \text{Sales Lost} + \sum \text{Sales Abandoned}} \quad (12)$$

◆ Cross validation

– Procedure for *thur gen*

- Set of C is partitioned randomly into ten subsets of equal size
- One is retained for validating the model, and nine are used as training data
- Performs ten more times and use mean hit rate

– Double cross validation for individualized Thurston's method *thur spec*

- 8 subset is for training set, one as optimization set, and one as for validation
- Compute general and individual scale values
- Optimize the weights for the linear combination of population and individualized scale vlaues
- 250 times performance and calculates mean hit rate

Data set

- ◆ Study 1: basic study (BS)
 - Comparing some newer image dependent gamut mapping with traditional benchmark
 - HPminDE and SGCK for reference algorithm
 - NOptStar, Kolas algorithm, Zolliker algorithm, and Caluori algorithm for spatial and image gamut mapping
 - 97 images
- ◆ Study 2: Image gamut (IG)
 - Uses image gamut description for gamut mapping
 - Linear and sigmoidal mapping
 - Source gamut, device gamut, and two types of image gamut description
 - Six possible combination above
 - 75 image

- ◆ Study 3: Local contrast (LC)
 - Comparison of details
 - HPminDE, SGCK, SGDA, and linear algorithm with and with out detail enhancement
 - 77 images and 5376 comparisons
- ◆ Study 4: Parameterized gamut mapping (PGM)
 - Parameters
 - Detail enhancement, color space, compression type, gamut size, color, lightness, and hue shifts
 - 97 images and 1536 and 5058 comparison

Table 1. Number of images, comparisons, and algorithms.

Study	Images	Comparisons	Algorithms
BS	97	2086	7
LC	77	5376	8
IG	75	4360	8
PGM	97	5058	1536

Experimental results

◆ Analysis

- SSIM has the best performance
 - On BS, LC, and IG, higher than competing measures
 - On PGM, close behind the best of the other methods
- Thurston's method are not significantly better than other measures
 - On BS, SSIM is better
 - Inefficient
- Individualized Thurstones's method
 - On LC and IC, better results
 - On BS and PGM, worse results
 - Better than Thurston's method



Fig. 1. The original image (on the left) and two gamut mapped images (in the middle and on the right).

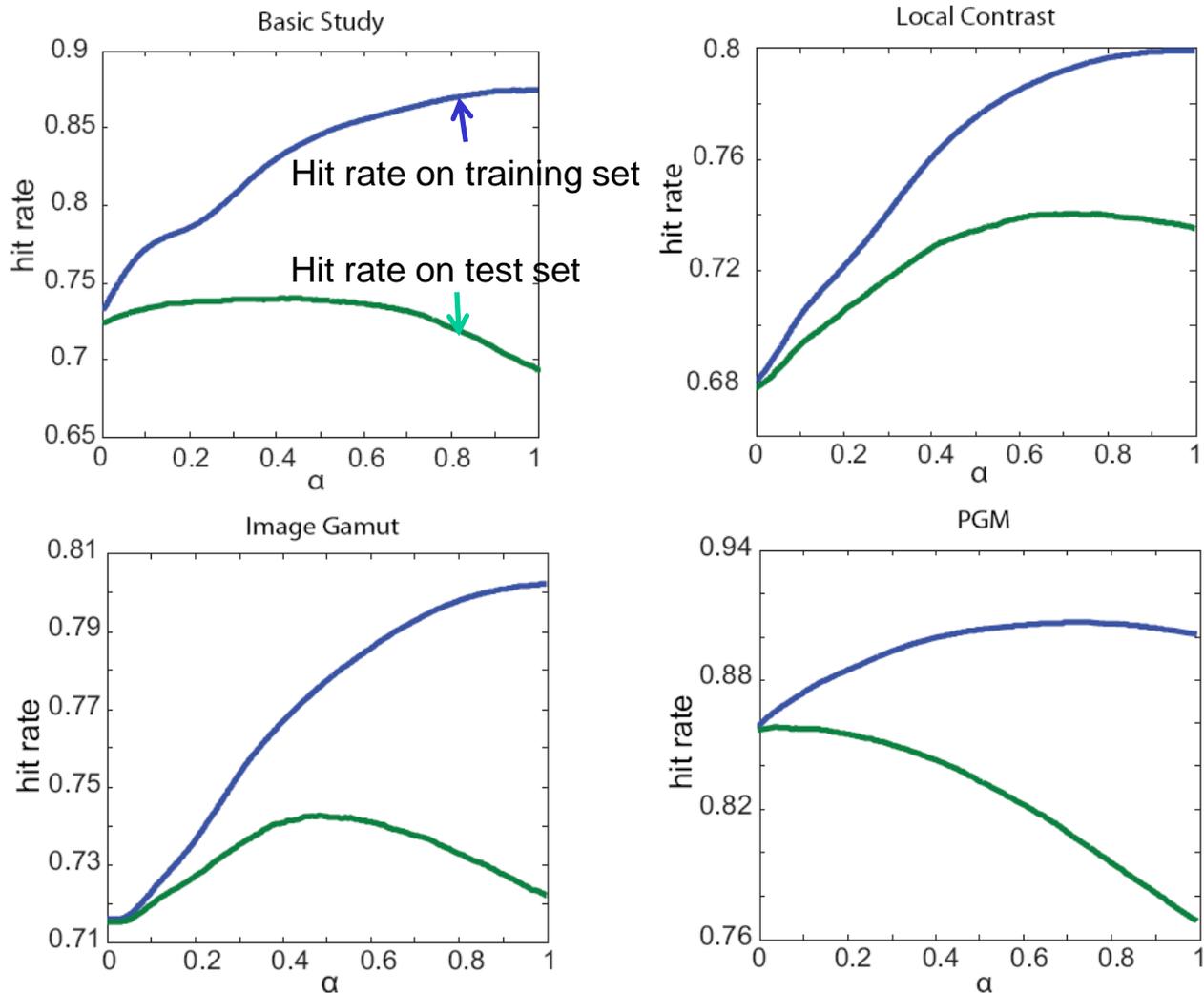


Fig. 2. Hit rates using Thurstone's method or conjoint analysis for:
 (a) Basic Study, (b) Local Contrast Study, (c) Image Gamut Study,
 and (d) Parameterized Gamut Mapping Study.

- On PGM
 - High hit rate due to easy comparison
 - Better result than the individualized conjoint analysis
- Combination of $Q_{\Delta E}$ and $Q_{\Delta LC}$ have the best results

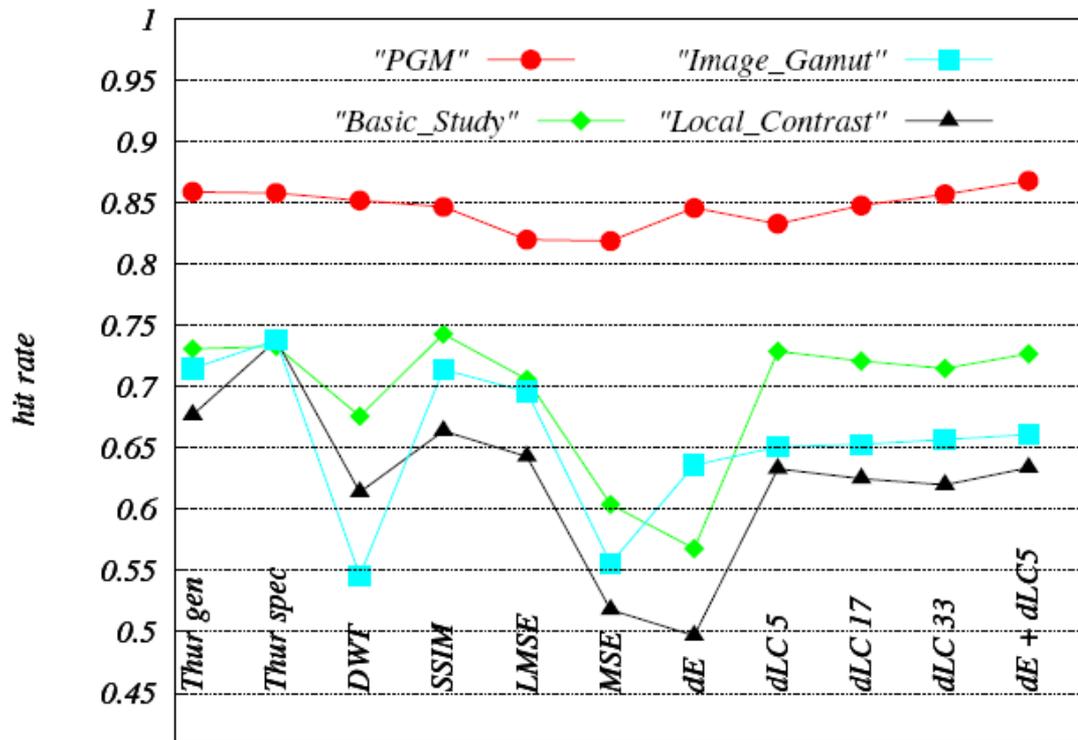


Fig. 3. Hit rates obtained by different methods for four studies.

Conclusion

- ◆ Comparison of image quality metrics
 - SSIM has the best results
 - Combination of measures of color difference and detail preservation is very promising
- ◆ SSIM is useful measure for gamut mapping comparing with psycho-visual test

◆ Thurstone's law of comparative judgement

- Compares between a series of stimuli
- To scale a collection of stimuli
- The law of comparative judgment applied to estimate scale values of the perceived weights

$$S_i - S_j = x_{ij} \sqrt{\sigma_i^2 + \sigma_j^2 - 2r_{ij}\sigma_i\sigma_j},$$

- S_i is the psychological scale value of stimuli i
 - x_{ij} is the sigma corresponding with the proportion of occasions on which the magnitude of stimulus i is judged to exceed the magnitude of stimulus j
 - σ_i is the discriminial dispersion of a stimulus R_i
 - r_{ij} is the correlation between the discriminial dispersions of stimuli i and j
- Pairwise comparison

The agent prefers x over y : " $x > y$ " or " xPy "

The agent prefers y over x : " $y > x$ " or " yPx "

- BTL model

$$\Pr\{X_{ji} = 1\} = \frac{e^{\delta_j - \delta_i}}{1 + e^{\delta_j - \delta_i}}$$

◆ Conjoint analysis

– Requires research participants to make a series of trade-offs

- A real estate developer is interested in building a high rise apartment complex near an urban Ivy League university. To ensure the success of the project, a market research firm is hired to conduct focus groups with current students. Students are segmented by academic year (freshman, upper classmen, graduate studies) and amount of financial aid received.

Study participants are given a series index cards. Each card has 6 attributes to describe the potential building project (proximity to campus, cost, telecommunication packages, laundry options, floor plans, and security features offered). The estimated cost to construct the building described on each card is equivalent.

Participants are asked to order the cards from least to most appealing. This forced ranking exercise will indirectly reveal the participants' priorities and preferences. Multi-variate regression analysis may be used to determine the strength of preferences across target market segments.