Regional Preference for the Rendition of People

Karin Töpfer, Elaine Jin, Scott O'Dell, Jayme Ribeiro, Eastman Kodak Company, Rochester, New York, USA

Abstract

Comprehensive studies of the preferred reproduction of skin tones were conducted in China and India, including: different cities in each country; groups of observers with different professional expertise, e.g., photofinishers and consumers; and different image capture sources, e.g., film and digital cameras. The obtained preferences were compared with previously published data for the United States and several Asian countries. Distinct differences in preference for skin tone reproduction were found by country, whereas the differences by city, professional expertise, and capture source, were smaller. A single mathematical model, with customized regional regression parameters, predicted the impact of skin tone reproduction on image quality in all different experiments. The results can be used to customize digital printing systems based on regional preferences for the rendition of people.

Introduction

Good skin tone reproduction is a desirable feature of pictorial imaging systems and is recognized as a parameter that can widely differ by geographic region. A recent study conclusively demonstrated different preferences for skin tone reproduction in three Asian countries and reviewed several earlier studies that showed regional differences in preference [1]. This result has practical significance because the majority of captured images contain people, and skin tone reproduction has been identified as one of the most important attributes affecting the color and tone quality of pictorial imaging systems [2a]. Modern digital output systems, e.g., digital minilabs, kiosks, and home printers, have the capability to address those regional preferences using digital image processing. It is important to build a knowledge base of preferred skin tone reproduction in different parts of the world so that this capability can be used. Results for China were reported previously [3], and the experiments were subsequently extended to India.

The problem of the preferred rendition of people is, however, more complex than reproducing the preferred chromaticities of skin tones, which we will refer to as skin color reproduction in this paper. Other color and tone attributes come into play, e.g., tone reproduction and color and density balance. Such attributes may determine how much detail is retained in black hair and delicate white clothing, how much additional color cast these items have, how smooth the faces look, and whether the overall image has a crisp appearance. Therefore, additional experiments were conducted in India and China to obtain the preferred settings of color and density balance and tone reproduction and to quantify the effect of deviations in these dimensions from the optimum on quality. These results were then compared with similar results obtained previously in North America (Rochester, New York) [2a] in order to develop an effective customization strategy for digital photofinishing in view of the many degrees of freedom that digital image processing offers.

Experimental Design

Prior to each of the field studies, the near optimum rendition of the scenes presented in the experiment (in terms of tone reproduction and overall color and density balance) was obtained with the help of local Kodak personnel. The selections were quantified using small Munsell N5 gray cards included in the images. As expected, the preferred balance was in the blue direction (CIELAB b* < 0) and lighter than in the United States (US). This was mainly driven by the desire to achieve a pleasing reproduction of skin tones. The approximate optimum was selected as the center point of the experimental design. The color balance and skin color variations represented a central composite design of nine a* and b* shifts centered on the estimated optimum skin tone reproduction. Four diagonal points represented small color differences in both a* and b* (1.5 to 4 units in each dimension). The four axial points produced larger variations in either a* or b* (CIELAB 1976 ΔE = 6 to 8). The levels of the color balance experiment were implemented as global shifts affecting the whole image. In the skin color reproduction experiments, variations in the chromaticity of skin tones were implemented as selective shifts affecting only the skin region of color space.

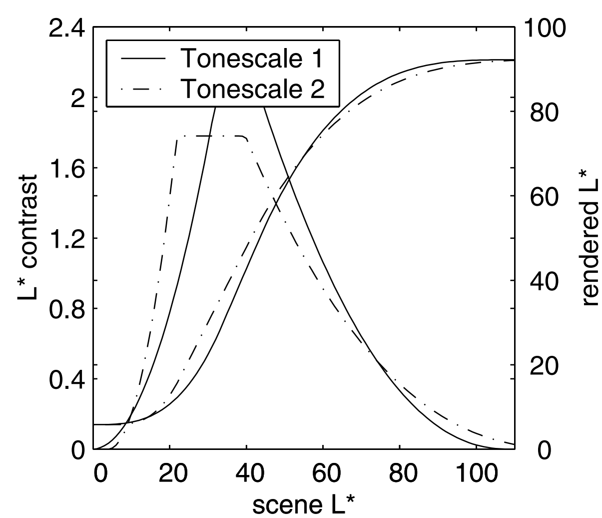

***Figure 1**. Typical tone reproduction curves and first derivatives (contrast).*

In China, variations in skin color were presented in conjunction with two different color balance positions of the images. The blue/cyan color balance position ("blue plane") approximately produced the preferred skin tone reproduction without any additional manipulations. The other color balance position ("neutral plane") represented a neutral balance with sub-optimum skin tone reproduction.

Print lightness was quantified based on five different CIELAB L* levels of a mid-tone neutral patch covering a total range of 25. The tone reproduction was characterized by the mapping of scene lightness (L*) to reproduced lightness in the printed image. Three overall contrast variations and one variation in shape were presented. Figure 1 shows two tonescales of different shape and somewhat different mid-tone contrast. Subtle changes in the slope of the tone reproduction curve can have a significant impact on the appearance of skin tones. Tonescale 2 has a lower maximum slope than tonescale 1, a longer region of constant slope in the mid-tone region, and softer highlight reproduction. These modifications compared with tonescale 1 can make skin appear significantly smoother by reducing the lightness and chroma differences in this important tonal region, while maintaining good overall contrast.

Image Processing

The image simulation pathway for all film-originated scenes is illustrated in Fig. 2. The color negatives were scanned on a Kodak DLS film scanner 1640 and converted to a reference printing density space, i.e., film densities "seen" by a reference photographic paper in a reference optical printer, using film-specific, one-dimensional lookup tables (1D LUTs) and matrices. A noise reduction step was included in order to keep any image quality degradations from image structure attributes small.

The purpose of the color and density balance step was either to reproduce each scene at a near-optimum position to center the experimental design, or to introduce controlled variations of these attributes for objective metric development. In a production setting, this step would be replaced by a scene balance algorithm and operator adjustments. The images were then rendered by mapping the balanced printing density values to ICC profile connection space (PCS [4]). Any variations in contrast and shape of the tone reproduction curve were included in this step.

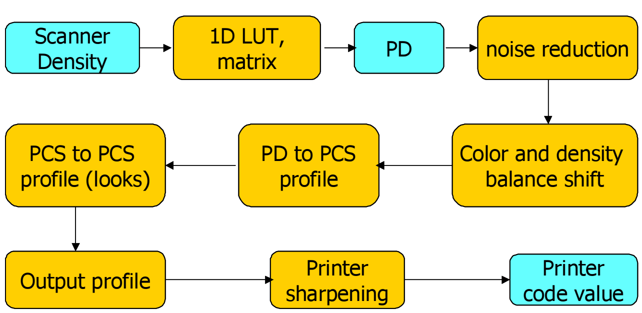

***Figure 2**. Image processing for scenes originating on film.*

In PCS, an optional effects profile was applied in order to smoothly modify certain parts of color space [5], e.g., skin colors. The effects profile contained any experimental variations in skin color. Finally, in order to print and view the image, an output profile to device code values was applied; appropriate sharpening was performed via unsharp masking to reach the desired sharpness; and the image was printed on a well-calibrated and characterized printer on Kodak Ektacolor Royal X paper.

Psychophysical Test Procedure

In each experiment, the observers were asked to rank-order 13 or 14 4 × 6-inch prints for each scene in terms of overall quality. All experiments were conducted under controlled lighting conditions using a GretagMacbeth Judge II light booth with CIE Standard D50 illumination. All observers passed standard visual acuity and color vision tests. In China, ten scenes captured on Kodak Gold 200 film and on three digital camera models were included in the skin tone and color balance studies. Additional experiments on tone reproduction were carried out with five levels and 35 different scenes. At least 30 observers participated in each study. Ten labs in four large cities in China (four in Shanghai, and two each in Beijing, Kunming, and Guangzhou) were chosen for the largest field study of skin tone reproduction. Eight participants per lab were recruited, including three lab operators and five store customers, for a total of 80 observers (30 photofinishing operators, 50 consumers).

In India, sixteen scenes captured on four different film types, including Kodak Gold 200 film, were presented in a combined skin color and tone reproduction experiment. The three large cities selected for the study allowed us to sample the full gamut of skin colors in India, with lighter skin dominating in Delhi, predominantly darker skin in Chennai, and a combination of both in Mumbai. Fifteen labs participated in the study, and six observers were recruited per lab, including four professionals (store manager/operator and professional photographers) and two consumers.

The rank-ordered data are equivalent to a full set of paired comparisons between the experimental levels. The proportions of selecting one sample over another in terms of quality were transformed to 50% just-noticeable differences (JNDs) of quality, which allowed us to build perceptually uniform scales and comprehensive models of image quality [2b].

Objective Metric for Color and Tone Attributes

Color quality metrics are intended to predict the perceived color and tone quality of images generated by an imaging system based on physical measurements of reproductions of representative test targets. The test targets in this case consisted of color patches that represented the centroids and gamut of natural Chinese, Indian, and Caucasian skin tones, as well as several neutral patches spanning the dynamic range of scene tones. These targets were subjected to exactly the same chemical and image processing as the test images. The reflection spectra of the target prints were measured on the Gretag Spectrolino Spectrascan and converted to CIELAB values for CIE Standard Illuminant D50. The image quality fall-off, as color reproduction deviates from the optimum position for each of the attributes, can be described by a weighted CIELAB color difference equation [2c]:

$$\Omega^{n_c} = \sum_{i=1}^{P} w_{i,p} \cdot \left(\sum_{j=1}^{V} w_{j,v} \cdot \Delta v_{i,j}^{n_c} + \text{additional terms} \right)$$

$$\text{(where } \sum_{i=1}^{P} w_{i,p} = \sum_{j=1}^{V} w_{j,v} = 1) \qquad (1),$$

where Ω is the objective metric raised to the power $n_c = 1$ or 2; $w_{i,p}$ is the patch weight given to the i^{th} of P patches; $w_{j,v}$ is the variable weight given to the j^{th} of V variables characterizing some aspect of color and tone reproduction, and $\Delta v_{i,j}$ is the difference between the actual reproduction of the i^{th} patch of the j^{th} such variable and the preferred position, $v_{i,j,0}$,. Most metrics are based on several color patches, which can have different weighting. The patches are mostly selected such that they span the natural range of occurrence of a color, e.g., skin tones. The *v* variables can represent CIELAB lightness (L*), hue and chroma, or a* and b*. Not all variables are needed for all attributes. Skin color and color balance can be described based on a* and b* differences; the metric for print lightness is based on the CIELAB L* value of a mid-tone neutral patch. The objective metric for tone reproduction requires several neutral patches to quantify the differences in lightness slope between the actual and optimum reproduction. All included dimensions of color (the Δv variables in Eq. 1) can have different weights $w_{j,v}$, as equal color differences in these dimensions have a different impact on quality. "Additional terms" reflect interactions between the dimensions of color.

In many studies, the quality loss in terms of 50% JNDs, ΔQ, with respect to the optimum (preferred) position, has been modeled as a function of the objective metric, Ω, using the integrated hyperbolic increment function (IHIF [2d]):

$$\Delta Q(\Omega) = \frac{R_r}{\Delta\Omega_\infty^2} \cdot \ln\left(1 + \frac{\Delta\Omega_\infty \cdot (\Omega - \Omega_r)}{R_r}\right) - \frac{\Omega - \Omega_r}{\Delta\Omega_\infty} \qquad (2),$$

with the fit parameters Ω_r as the objective metric value at threshold, R_r as the radius of curvature at threshold, and $\Delta\Omega_\infty$ as the asymptotic objective metric change corresponding to one JND well above threshold. This form of the IHIF applies when $\Omega > \Omega_r$; elsewhere $\Delta Q = 0$.

The general form of the equations was the same in all regions, i.e., China, India, and North America. However, different regression parameters ($w_{j,v}$ and $v_{i,j,0}$ in Eq. 1) and in the IHIF (Eq. 2) reflected different preferences and sensitivities to each attribute in the regions. The regression parameters in Eqs. 1 and 2 were co-optimized using a nonlinear regression routine.

Further insight can be gained if preferences are analyzed for individual observers and scenes. This allows us to obtain a preference distribution, which is a probability density function quantifying the relative frequency with which different values of an objective metric are preferred.

Results and Discussion

All data obtained in pilot and field studies in China and in India were quantified in terms of 50% JNDs of quality loss with respect to the optimum color and tone position at zero JNDs. As expected for preferential attributes, the optima were scene- and observer-dependent, and varied significantly by region. Preference (regression parameters in Eq. 1) and quality loss parameters (regression parameters in Eq. 2) were obtained for each attribute studied (skin color, tone reproduction, and color and density balance), and for different subgroups of observers and scenes, including the mean over all observers and scenes by country.

Figure 3 shows the contours corresponding to 50% of peak preference (dotted lines) and the –1 JND quality loss contours (solid lines) for skin color reproduction by region in a CIELAB b* vs. a* plot. The center of each ellipse corresponds to the preferred rendition of the typical, i.e., most frequently occurring, skin tone in each country. Preferences for the rendition of Caucasian and Asian skin tones differ substantially, as indicated by the large differences in the positions of the ellipses. More reddish and desaturated renditions of skin color were preferred in India and China. The preferred skin tone reproduction previously reported by Yamamoto [1] for China falls inside the contour corresponding to 50% of the peak preference, indicating good agreement.

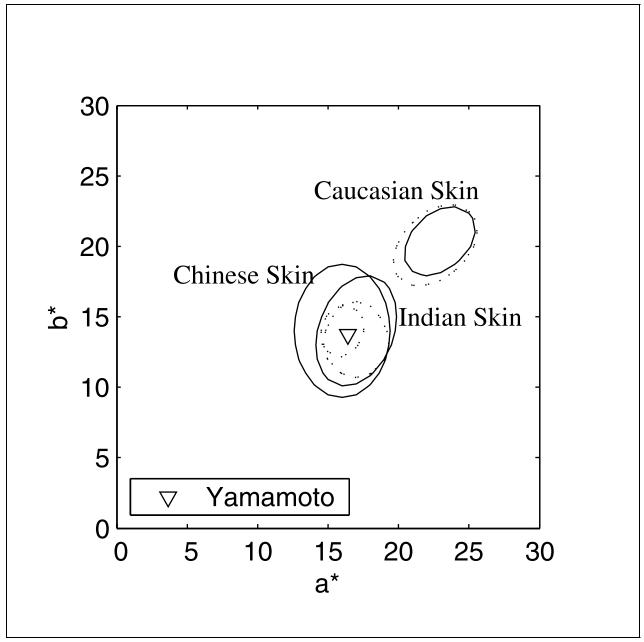

***Figure 3**. 50% preference (dotted line) and -1 JND quality loss (solid line) contours for the rendition of the typical skin tone by region in a CIELAB plot. The preference distribution obtained in China is the small, inner ellipse.*

The contours for India and China overlap, which suggests that similar appearances of skin tones are preferred in both countries. This, however, requires different color and density balance shifts in photofinishing, because the average natural skin color differs in both countries. Although not shown in the figure, these differences also extend to the lightness dimension. Indian skin tones show a wider variety in lightness than Chinese skin tones, and are on average somewhat darker. The preferred overall print lightness, quantified by the Munsell N3.5, however, is highest in India, followed by China and the US.

Moreover, the orientation of the ellipses changes by region. This result is important in terms of system robustness. For Caucasian skin tones, hue is the most important attribute, as illustrated by the narrowness of the contour across the diagonal. Wider variations in hue were tolerated in China, indicated by the orientation of the ellipses parallel with the b* axis, whereas shifts along the red-green axis (a*) were most detrimental to image quality. Surprisingly, individual preferences for the rendition of skin color showed much less variation in China compared with India and the US, as indicated by the area enclosed by the respective preference distributions. This result, combined with the larger tolerance towards deviations from the optimum reproduction, suggests that the potential for customization in China is smaller compared with that of the other two locations.

The results shown in Fig. 3 provide a strong argument for regional customization of digital photofinishing. Further customization within a region, however, might not be necessary. Results previously reported for China [3] were confirmed in India. In particular, there were no significant differences in preference between any of the selected subsets within a region, i.e., by city, by capture (digital and film types), by color cast of the background in the skin tone study (neutral vs. blue), and between photofinishing operators and consumers.

The best strategy for the customization of digital photofinishing can be inferred by analyzing the quality benefits from rendering the images at a regionally optimized color and tone position compared to the optimum rendition for the US. The data for color balance, print lightness, and skin color were calculated based on the image quality models according to Eqs. 1 and 2 with regionally optimized regression parameters. The large magnitude of the improvement for skin color compared with the relatively modest improvement from global color and density shifts confirms that adjustments of the latter two attributes are mainly driven by the desire to obtain pleasing skin tones. This would suggest that the best strategy for regional customization is the implementation of an effects profile in PCS that selectively moves skin tones to the preferred position while retaining a near neutral balance of other colors. However, a direct comparison of this approach with global color and density balance shifts that produce the same preferred skin position suggests that the simpler global approach is as effective in achieving the optimum quality. Both approaches were equivalent in terms of overall quality. Because of its simplicity, the global method is preferable in terms of robustness and maintenance.

Table 1: Magnitude of quality improvements, ΔJND, from regional and individual customization for various color and tone attributes.

Quality improvement	ΔJND China	ΔJND India
Tonescale 2 – Tonescale 1	0.4	0.6
Print lightness (region – U.S.)	0.1	0.5
Color balance (region – U.S.)	0.6	0.6
Skin color (region – U.S.)	2.4	2.9
Neutral – blue background	0.0	0.0
Full skin customization – best system color and tone		
Professionals	0.6	1.1
Consumers	0.3	0.3

The quality benefit of rendering skin tones at the preferred position for each individual observer and scene combination (full customization) compared to the best compromise system position can be estimated from the rank that was assigned to the latter position. As expected, full control over the rendition of skin tones via a user interface is important for professionals (leading to an average quality improvement of 1.1 JNDs in India), but not in a production setting for consumers. Individual customization is particularly important in India and the US, where preferences varied widely, and deviations from the optimum quickly degraded quality. Consequently, the quality benefit from customization listed for India in Table 1 is larger than it is for China.

The average quality improvement from the change of the tonescale shape, which was 0.4 to 0.6 JNDs in China and India, might seem modest. However, the data from China suggest that professionals, who are important decision makers in purchasing photofinishing equipment, perceive a larger difference of up to one 50% JND.

Conclusion

The complex subject of regional preference for rendition of people was tackled by quantifying the effect of variations of several important color and tone attributes, i.e., skin color reproduction, tone reproduction, and color and density balance, on 50% JNDs of quality. The simplest, most effective, and robust customization strategy in digital photofinishing is the development of a tonescale optimized for skin tone reproduction in combination with global color and density balance shifts. Manual controls for individual customization provide additional quality benefits for professional customers, e.g., photographers and photofinishers.

Acknowledgements

We thank Henri Hu, Judy Xu, Bob Chen, and Jessica Hu of Kodak (China) Company Limited for their help with image capture and pilot studies. Professor Xiuying Qian of Zhejiang University and Bhavani Suryavanshee of Kodak India Limited conducted the field studies in China and India, respectively.

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Author Biography

Karin Töpfer received her Masters degree in Physics from Dresden University of Technology and a Ph.D. in Photophysics from Dresden University of Technology. Since 1993, she has worked at Eastman Kodak Company, first in the UK and later in Rochester, NY. In recent years, her work has primarily focused on predictive image quality modeling, including color quality, and on psychophysics. She has recently extended this expertise to medical imaging systems. She is the co-author of three chapters in the Handbook of Image Quality: Characterization and Prediction (New York: Marcel Dekker, 2002, ISBN 0-8247-0770-2).