Memory Color Enhancement Algorithm

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Abstract

We introduce an algorithm that squeezes colors toward preferred point in color space. This preferred point could be the optimal skin, sky, grass, or spot color, or any other important color. No segmentation of the image is used to isolate the colors of interest, which has two advantages: first, no artifacts are introduced in the transitions between adjusted and unadjusted colors, and second, the algorithm can be implemented as a look-up table, fitting nicely into the ICC paradigm. Psychophysical testing showed the algorithm gave equal or improved rendition over the unadjusted originals.

Introduction

Since man began capturing the human face in art, there has been a desire to produce the most pleasing color rendition of flesh. Pierre-Auguste Renoir is quoted as saying, "I never think I have finished a nude until I think I could pinch it." Today, pictures of friends and family are among the most common subjects of digital photography, and the demand for high-quality images continues to rise.

Scientists have been working on determining the ideal color of skin for decades. Early color scientists such as Bartleson [1,2], Macadam [3], and Hunt [4] performed experiments asking observers to indicate most pleasing flesh tone. Extensive research at Chiba University has considered the best reproduction of skin tones in print media and on displays [5-10]. Blommaert et al have aimed to developing metrics for the naturalness of skin images [13-15]. Several other references on skin tone reproduction have been included [14-16]. In addition, several databases have been compiled that indicate the colorimetric coordinates of real skin tones [17,18].

This current research leverages those studies of optimal skin tone into an algorithm that adjusts all images toward that optimum. The algorithm can also be used for other important memory colors such as sky and grass, but this work focuses on the results of a skin tone study [19,20].

The crux of the algorithm is a method to squeeze colors toward a preferred point in color space. Squeezing is used rather than rotation since the input skin hue is unknown. The squeezing is applied to entire images without the need for segmentation, to improve skin tones. It will, of course, affect objects that are not skin but are skin-colored. In our experiments, people didn't seem to mind the change in these objects and focused mainly on skin in the images. If desired, segmentation could be used to locate skin or identify whether an image has skin in it at all, but then applying the algorithm to the entire image.

The best results were found when the preferred point is specified by its CIELAB hue angle and chroma, and squeezed only in hue, but over a limited chroma range. The literature did not indicate a strong need to vary the algorithm over lightness.

Squeezing Algorithm

The algorithm shifts hue as described in Eq. 1. The amount of change from input to output ("hue change") is weighted by how far the output hue is from the optimal hue.

$$H\_out = H\_in - delta\_H \times weight\_h \times weight\_C \qquad (1)$$

where *delta_H* = *H_in* - *H_pref*, and *weight_C* is given by Gaussian function and weight_h is given by the addition of two Gaussian functions. These Gaussians are separated by a distance *M*, and are centered around the input hue, *H_in*. The form of this weighting function is given by eq. (2).

In an earlier instantiation of this algorithm, a simple Gaussian was used for *weight_h*, but it was found that this resulted in a hue-in-to-hue-out relationship that has a slope of zero at the preferred hue angle. This resulted in a region around the preferred hue getting mapped to a single hue. The resulting images showed a unnatural lack of hue variation in the skin tones.

By modifying the weighting function to be the addition of two Gaussians, there results a region around the preferred hue angle where little or no adjustment takes place. This algorithm can be described by Eq. 1, but where the weight for hue has been modified as shown in Eq. 2-3.

$$weight\_h = K \times weight\_tmp \,/\, \max(weight\_tmp) \qquad (2)$$

$$weight\_tmp = e^{\frac{-(H\_in-M)^2}{2*H\_sigma^2}} + e^{\frac{-(H\_in+M)^2}{2*H\_sigma^2}} \qquad (3)$$

M controls the separation between the Gaussians, and thus the size of the "safe" region around the preferred hue angle. *K* is a scaling function that keeps the hue-in-to-hue-out relationship monotonic. *K* was chosen empirically in this study to give the appropriate behavior.

The parameters in Eq. 4 were determined from looking at the optimal flesh hue as determined by earlier studies, as well as some experimentation.

$$\begin{aligned} &H\_pref = 45 \quad C\_pref = 25 \\ &H\_sigma = 20 \quad C\_sigma = 10 \\ &M = 30 \quad K = 0.6 \end{aligned} \qquad (4)$$

The weighting functions for the parameters used in this study are shown in Fig. 1.

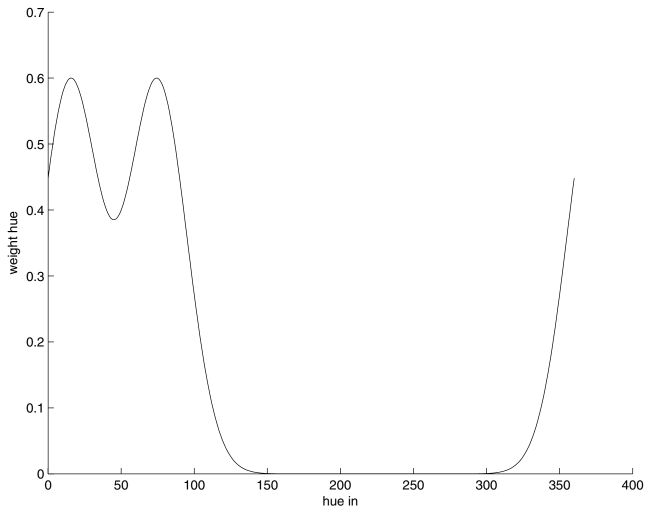

Fig. 1. Hue weighting function, weight_h as a function on input angle, where the preferred hue angle is 45 degrees.

The relationship between *hue_in* and *hue_out* for the weighting functions and parameters given in this report is shown in Fig 2.

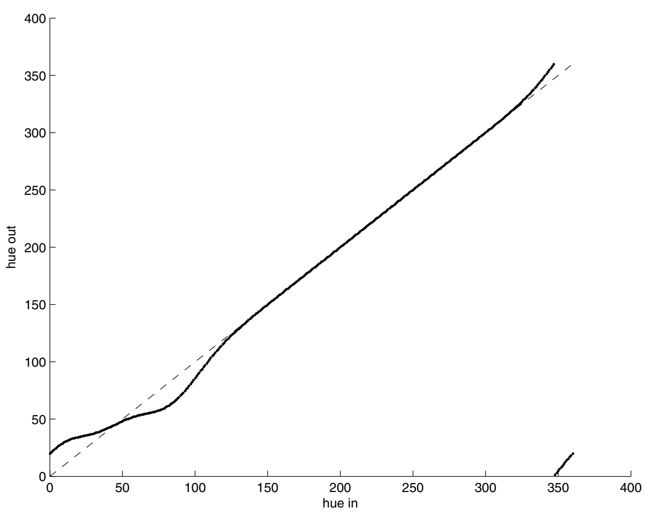

Fig. 2. The resulting effect of the hue squeezing using the double-Gaus method. The double-Gaus method more gradually compresses near the preferred hue angle than a single-Gaus function.

Psychophysical Experiment

Fifteen consumer-quality images were selected from among digital camera pictures taken by some of the observers in the experiment. Three examples are shown in Fig. 4 along with the corrected images. Seventeen color-normal observers compared the uncorrected images from digital cameras to those with the squeezing algorithm applied for all the images. Observers were asked to select the image they preferred. Image content was primarily of Caucasian subjects, and observers were primarily Caucasian. One observer and one image subject, *gsharma1*, were Indian.

Fig. 3 shows the results. The images are labeled along the x-axis according to whom the image belonged. The black bar shows the percentage of people who preferred the hue-squeezed images and the white represents the percentage who preferred the uncorrected image. The smiley faces represent the opinions of the first-party observers. For example, observer J. Stinehour preferred the new algorithm to the original for *jstinehour1* and for *jstinehour2*, Observer N. Zeck preferred the squeezing algorithm for *nzeck1* and *nzeck2*, but not for *nzeck3*. Those observers are expected to be the most critical for those images. Their results agree very well with the average observer.

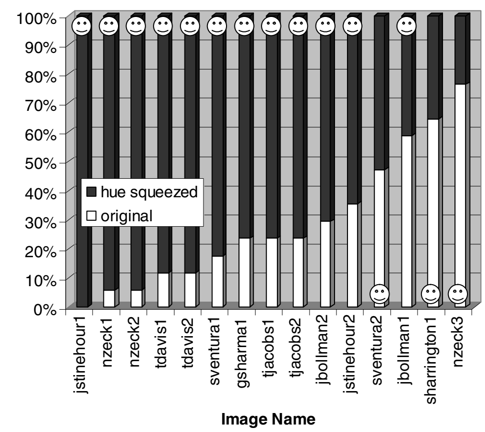

Fig. 3. Results of image quality experiment. The labels indicate the observer with whom the images are associated. The red bar indicates the percentage of observers who preferred the corrected image to the original (blue). The smiley face indicates whether the observer with whom the image is associated preferred the corrected (smiley at top) or original image (bottom).

In order to see if the results for each image were significantly different, a two-tailed test was again performed for $\alpha = 90\%$ and as described in Eq. (5).

H_0: $p = ½$

Test statistic: $(V-np)/\text{sqrt}(np(1-p))$ (5)

Critical region: $C = \{z: z <= -z_{\alpha/2} \text{ or } z >= z_{\alpha/2}\}$

The null hypothesis was accepted for four of the images in Fig. 3, namely *jstinehour2*, *sventura2*, *jbollman1*, and *sharrington1*, thus these adjusted images could be considered equivalent to the originals. In image *sharrington1*, the subject's shirt noticeably changed hue, possibly offsetting any improvement from the change in skin tone. The squeezing algorithm improved 10 of 15 images. For *nzeck3*, the only image where the adjusted image was not preferred by a stastically significant amount, the original and squeezed images were very close, so it was surprising that the results were as decisive as 76%-vs-24%. The squeezing algorithm removed a slight pinkishness from the lady's cheeks, perhaps leading to the preference for the original.

Conclusions

The hue-squeezing algorithm gave improved results for 10 of 15 test images, and statistically equivalent results for 4 of the 15 images. The parameters will be further optimized through additional experiments, tested for images and observers of other races, and tested with images that contain skin-colored (but not skin) objects. Also, the algorithm will be tested on other memory colors, such as sky and grass.

References

[1] C.J. Bartleson, "Some Observations on the Reproduction of Flesh Colors," *Phot. Sci. and Eng.* **3**, 114-117 (1959).

[2] C.J. Bartleson and C.P. Bray, "On the Preferred Reproduction of Flesh, Blue-Sky, and Green Grass Colors," *Phot. Sci. and Eng.* **6**, 19-25 (1962).

[3] D.L. MacAdam, "Quality of Color Reproduction," *J. SMPTE* **56**, 487-512, (1951).

[4] R.W.G. Hunt, I.T. Pitt, and L.M. Winter, "The Preferred Reproduction of Blue Sky, Green Grass, and Caucasian Skin in Colorur Photography," *J. Phot. Sci.* **22**, 144-149 (1974).

[5] D. Sanger, T. Asada, H. Haneishi, and Y. Miyake, "Facial Pattern Detection and Its Preferred Color Reproduction," *Proc. 2nd IS&T/SID Color Imaging Conference*, Scottsdale, Arizona; 1994; p. 149-153.

[6] F.H. Imai, N. Tsumura, H. Haneishi, and Y. Miyake, "Prediction of Color Reproduction for Skin Color Under Different Illuminants Based on Color Appearance Models," *J. Imag. Sci. and Tech.* **41**, 166-173 (1997).

[7] F.H. Imai, N. Tsumura, H. Haneishi, and Y. Miyake, "Principal Component Analysis of Skin Color and Its Application to Colorimetric Color Reproduction on CRT Display and Hardcopy," *J. Imag. Sci. and Tech.* **40**, 422-430 (1996).

[8] F.H. Imai, N. Tsumura, H. Haneishi, and Y. Miyake, "Spectral Reflectance of Skin Color and its Applications to Color Appearance Modeling," *Proc. 4th IS&T/SID Color Imaging Conference*, Scottsdale, Arizona; 1996.

[9] N. Ojima, H. Haneishi, Y. Miyake, "The Appearance of Skin with Make-up (III) (Estimation for spectral reflectance of skin with the HDTV color image)," *J. SPSTJ* **57**, 78-83 (1994) in Japanese.

[10] H. Haneishi, M. Myodo, H. Yagushi, and Y. Miyake, "Trial of Preferred Colour Reproduction in Hardcopy of Still Video Images," *J. Phot. Sci.* **41**, 78-79, 1993.

[11] T. J. W. M. Janssen and F. J. J. Blommaert, "Predicting the Usefulness and Naturalness of Color Reproductions," *J. Imag. Sci. and Tech.* **44**, 93-104 (2000).

[12] S.N. Yendrikhovskij, F.J.J. Blommaert, and H. de Ridder, "Color Reproduction and the Naturalness Constraint," *Color Res. & Appl.* **24**, 52-67, 1999.

[13] E. A. Fedorovskaya, H. de Ridder, F.J.J. Blommaert, "Chroma Variations and Perceived Quality of Color Images of Natural Scenes," *Color Res. & Appl.*, **22**, 96-110, 1997.

[14] T. Yano, K. Hashimoto, "Preference for Japanese Complexion Color under Illumination," *Color Res. & Appl.* **22**, 269-274, 1997.

[15] P. Bodrogi, T. Tarczali, "Colour Memory for Various Sky, Skin, and Plant Colours: Effect of the Image Context," *Color Res. Appl.* **26**, 278-289 (2001).

[16] K. Töpfer and R. Cookingham, "The Quantitative Aspects of Color Quality Rendering for Memory Colors," *Proc. PICS 2000: Image Processing, Image Quality, Image Capture, Systems Conference*, Portland, OR; March 2000; p. 94-98.

[17] The University of Oulu Physics-Based Face Database, http://www.ee.oulu.fi/research/imag/color/pbfd.html.

[18] M. Vrhel, R. Gershon and L. Iwan, "Measurement and analysis of object reflectance spectra," *Color Res. & Appl.* **19**, 4-9 (1994).

[19] K. Braun, "Method for squeezing an input hue toward a region of preferred hue," *US Patent Appl. 20050041857*.

[20] K. Braun, "Method for determining a hue adjustment to an input hue," *US Patent Appl. 20050041853*.

Author Biography

Karen Braun has been a researcher in the Xerox Innovation Group since 1996. Her work is focused on color image processing, pre-press innovations, and the human color experience. She received her B.S. in Physics from Canisius College in 1991 and her Ph.D. in Imaging Science from RIT in 1996. She is has participated on the IS&T/SID Color Imaging Conference technical committee for many years and is an active member of both IS&T and Inter-Society Color Council (ISCC), for which she has served on the Board. She has published extensively in the areas of gamut mapping and color appearance, and co-edited IS&T's Recent Progress in Color Science *with Reiner Eschbach.*