Color Appearance and Spatial Related Color Gamut Mapping

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Abstract

This paper proposes an algorithm named Color Appearance and Spatial Related Color Gamut Mapping(CASRCGM).This algorithm is using the image Color Appearance Model (iCAM) as standard connection space. Color appearance attributes like lightness (J), chroma (C), and hue (h) as mapping variables are used for color gamut mapping. Confirmatory experiments of CASRCGM were based on a digital workflow with color inkjet printer. Eight digital originals were transformed from source image gamut to target printer's gamut. Control group was tested with CIE recommended Algorithms HPMinΔE and SGCK. After pairwise comparisons on monitors, psychophysical visual evaluation on images after mapping were carried out. The results indicated that the proposed Algorithm are better than those recommended by CIE in mapping accuracy and uniformity of color appearance.

Introduction

The gamut mapping methods based on Image-Device is to achieve mapping regarding the relationship between color characteristics of image itself and characteristics of device. They have the advantages that gamut mapping methods based on device-device do not have. Taking into account the spatial distribution of image pixels and their characteristics of mutual interaction among neighboring pixels, spatial gamut mapping method is the main development direction of image-device algorithms. By spatial gamut mapping methods, in addition to considering the color informations of the pixels themself from source image, their mapping process are also effected by the color informations of other neighboring pixels to the one pixel in concern. In this way, the greatest degree of spatial relationship among color informations of the source image can be preserved[1-3].

During the transfer of source image to target medium, it is impossible to keep color information of image intact. However, the purpose of display image based on high-fidelity color reproduction is for human eye to observe, in order to obtain a satisfactory quality for evaluation with human visual, therefor so long as reproduction accuracy of color information and relationship among color informations achievers a retainable optimal balance. According to the above, this paper proposes a genre of mapping algorithm using image color appearance attributes such as lightness (J), Chroma (C) and hue angle (h) as the mapping variables, Image Color Appearance Model (iCAM) as standard connection space, it is called Color Appearance and Spatial Related Color Gamut Mapping (CASRCGM). This algorithm can distinguish characteristics like color informations of each pixel and color appearance attributes perceived by human eye under different viewing conditions, by keeping the relative visual perception of each pixel from original image steady, uniformity of color visual appearance for image color information after mapping can be achieved.

It is one of the most common examples of high-fidelity color information reproduction that color information is transferred from monitor to printer. This paper take digital color inkjet printing workflow as an example, algorithms for CASRCGM is discussed and analyzed.

CASRCGM algorithm

Algorithm framework

Within spatial gamut mapping algorithm, mostly through image decomposition, the image is decomposed into image with low-frequency components and image with high-frequency components, then with point-by-point color gamut mapping methods, in other words, with methods of gamut clipping and gamut compression, low-frequency image shall be mapped into target gamut, then image with high-frequency will be mapped into target gamut, after that, high-frequency detail part of the source image will be superimposed into the mapped image[4]. If the superimposed image extends outside of the target color gamut boundary, then through implementation of an iterative process, all pixels from the source image are mapped into the corresponding target colors within the color gamut. Taking into account that color appearance model space (PCS) as connection space and color appearance attribute as mapping variables, CASRCGM algorithm framework model can be given as shown in Figure 1.

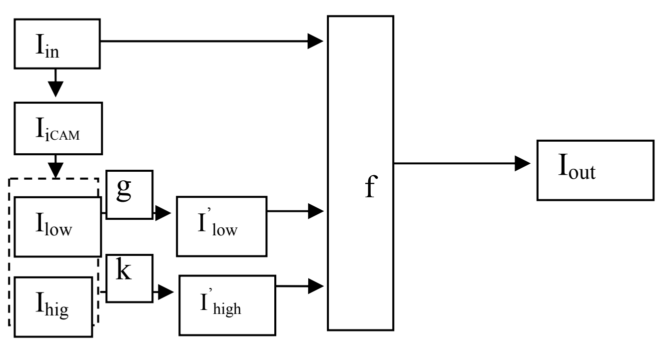

***Figure 1**. basic framework of CASRCGM algorithm*

According to the algorithm framework shown in Figure 1, the algorithm can be expressed by the equation (1):

$$I_{out} = f\left[I_{in}, I_{iCAM}, g(I_{low}), k(I_{high})\right], I_{out} \in Gamut_{Dest} \quad (1)$$

Wherein, I_{out} is the result image of the spatial mapping, $Gamut_{Dest}$ represents target gamut, f, g and k are different gamut mapping algorithms. Typically, f, g and k are chosen based on algorithms that can keep the values of pixels in image and their relationships among the pixels in their neighborhood.

Algorithms principles and calculation process

The basic process of Algorithm of CASRCGM is as following. At first, with GOG model (Gain-Offset-Gamma), the signal values dR, dG, and dB of each pixel in source image are converted to CIEXYZ tristimulus values, this process is achieved by forward colorimetric characterization of monitor. Then according to the surround of the displaying monitor and the characteristics of its lumination, color appearance attributes of each pixel in source image can be obtained through forward transform with color appearance model iCAM, the attributes are lightness (J), chroma (C) and hue angle (h). As iCAM color appearance attributes were calculated, the surround of the displaying monitor were set to "darker luminance," let F = 0.9, c = 0.59, Nc = 0.95. the surround parameters of prints were set to "average luminance," Let F = 1.0, c = 0.69, Nc = 1.0. Within the ICAM color appearance model, the low-pass filtered image was treated as adaptation field, luminance channel of the low-pass filtered image was treated as adapting luminance, the surround luminance of low-pass image was treated as surround luminance[5,6].

The calculation process is as following:

Step1: determination of relationship between RGB scalars and color signals dR, dG, and dB from source image.

This paper uses Gain-Offset-Gamma model (GOG)of analytic method identified the relationship between three primary scalar R, G, and B values and color signals dR, dG, and dB. Assume (1) RGB three channels are independent of each other, and they do not affect each other; (2) chromaticity coordinates of CRT phosphor remain constant, that is, they does not change because of the signal values; (3) temporal constancy; (4) spatial independency. Then there are a

$$L_r = \begin{cases} L_{r,\max}[k_{g,r}(\frac{d_r}{2^N-1})+k_{o,r}]^{r}, [k_{g,r}(\frac{d_r}{2^N-1})+k_{o,r}] \geq 0 \\ 0, [k_{g,r}(\frac{d_r}{2^N-1})+k_{o,r}] < 0 \end{cases} \quad (2)$$

Let dr, dg, and db represent the pixel values of source image, and let kg, i = 1, ko, j = 0, then a simplified formula can be obtained as following:

$$R = (\frac{d_r}{2^N-1})^{r_r} \quad (3)$$

$$G = (\frac{d_g}{2^N-1})^{r_g} \quad (4)$$

$$B = (\frac{d_b}{2^N-1})^{r_b} \quad (5)$$

Based on the condition under these specified assumptions, on the relation between tristimulus values X, Y and Z of one certain pixel and the three primary colors scalar R, G and B of that pixel, and on the formula (3) (4) (5), relation between X, Y and Z and signal values dr, dg, and db can be obtained:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = A \begin{bmatrix} (\frac{d_r}{2^N-1})^{r_r} \\ (\frac{d_g}{2^N-1})^{r_g} \\ (\frac{d_b}{2^N-1})^{r_b} \end{bmatrix} \quad (6)$$

In above, A is a characteristic matrix, representing the tristimulus values of a pixel and its scalar, in other words, the linear transformation relationship between the normalized luminance values of the three channels.

Step2: Calculation of color appearance attributes from the source image pixels with iCAM.

Since iCAM duplicating field is different with other color appearance models, take the low-pass filtered image as the adapting field, at the first, the source image is low-pass filtered:

$$(XYZ)_{adapt} = LowPass((XYZ)_{stim}) \quad (7)$$

Whereas (XYZ)stim means tristimulus values of source image pixels that obtained in Step1, (XYZ)adapt is tristimulus of low-pass image pixel after low-pass filtering, LowPass means the filtering process. Then after the calculation step for color appearance attributes with iCAM, the color appearance attributes of the source image can be obtained, namely lightness (J), chroma (C) and hue angle (h).

Step3: complete color appearance attributes related gamut mapping from source gamut to target gamut.

Using respective color appearance attributes of source color gamut and target color gamut obtained by the above process, and then according to the formula (8) and (9), color appearance attributes related gamut mapping was conducted:

$$J_r^* = J_{r(\max)}^* - (J_{o(\max)}^* - J_o^*)\frac{(J_{r(\max)}^* - J_{r(\min)}^*)}{(J_{o(\max)}^* - J_{o(\min)}^*)} \quad (8)$$

$$D_C = \begin{cases} S_C; S_C \leq J_C \\ J_C + 4(G_{D\max C(J,h)} - J_C)(\xi - \xi^2); J_C < S_C \leq G_{S\max C(J,h)} \end{cases} \quad (9)$$

Evaluation of Mapping results

Evaluation of mapping results with gamut mapping algorithm can use a combination of subjective and objective methods, which contains calculation method with color difference formula and experiment method on visual psychophysics simultaneously. Source images were selected from GATF 4.1 test images used for printing attribute analysis, such as neutral gray (# 1), group portraits (# 2), bright tone (3 #), Ms. portrait (4 #), the whole tone (# 5), memory colors (6 #) and dark tone (7 #), and standard color ECI2002R CMYK target (8 #), etc., shown in Figure 2.

Objective Evaluation Method

Objective evaluation is usually using color difference formula and reproduction color gamut, the common color difference formulas include CIE1976L*a*b*, CIEDE94, CIEDE2000. In iCAM color appearance model, the image color difference formulas is used in lightness, P and T space (IPT color space) for calculation. taking into account the convenience of calculation and the color reproduction process achieved in this paper, the choice of objective evaluation method is set for CIE1976 L*a*b* color difference formula and image color difference formula in IPT color space [7].

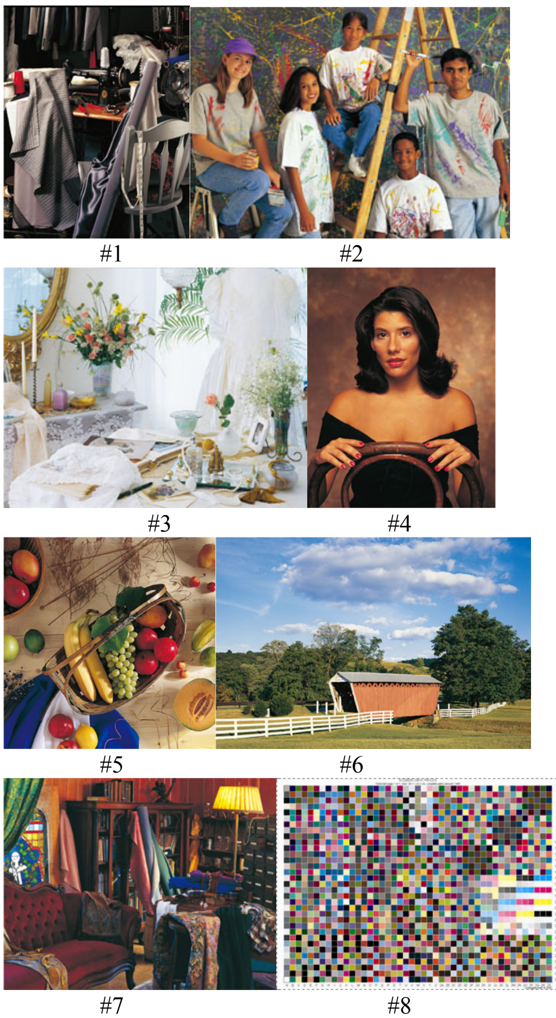

Figure 2. *Eight images used for evaluation of effect after mapping*

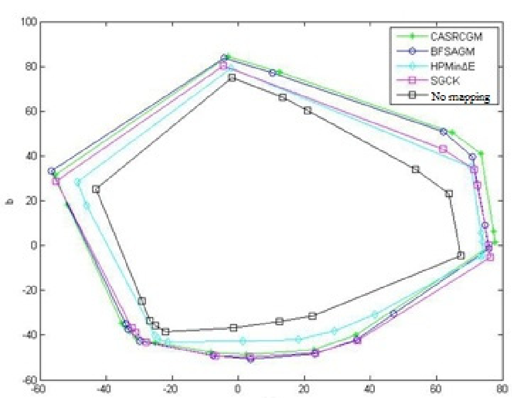

Figure 3. *Four kinds of color gamut mapping algorithms compare the output obtained after gamut*

In the experiments, based on Bilateral Filtering Spatial Adaptive Gamut Mapping (BFSAGM), Color Appearance and Spatial Related Color Gamut Mapping (CASRCGM), HPMinΔE algorithm and SGCK algorithm, the source image, the standard color ECI2002R CMYK Target (8#), are go through mapping and exported, respective output color gamuts are calculated, shown in Figure 3. From Figure 3 we can find out that CASRCGM algorithm and BFSAGM algorithm are better than HPMinΔE algorithm and SGCK algorithm in term of expansion of color reproduction gamut within the range of the target device, which reduce the lost of image color information."No mapping output" in Figure 3 means that gamut mapping source image are no longer processed, but directly go to output from digital inkjet printer.

For the calculation of color difference, on the basis of the ECI2002R CMYK standard target, the paper design and output 108 patches, Epson Stylus Pro7880C as output device, and EFI digital workflow control software, color measurement instruments are X-Rite Eye-one io, viewing conditions is D65/2°, results of calculation of color difference are shown in Figure 4. Figure 4 shows that, the color difference between output image after the gamut mapping process and original image is significantly less than the color difference between direct output image without mapping process and original image, that is to say, CASRCGM algorithms proposed in this paper is superior to HPMinΔE and SGCK algorithms.

Psychophysical visual experimental method

Currently in the color reproduction, methods of psychophysical visual experiment used in quality evaluation of gamut mapping algorithms are mainly categorized into pairwise comparison methods, classification methods and sorting methods. Among them, the paired comparison methods have high prediction accuracy, their implementation process is simple and quickly, they are more widely used then other quality evaluation methods of gamut mapping[8,9].

In Experiments BFSAGM algorithm, CASRCGM algorithm, HPMinΔE algorithm and SGCK algorithm were used respectively, for 8 color images in Figure 2, mapping is from color gamut of original image to the mapping target gamut of a inkjet printer. Then psychophysical visual assessment was carried out made using comparative judgments method proposed by Thurstone[10]. experiments carried out with EIZO ColorEdge CG211 monitor, in order to examine the effect of differences in the mapping using those algorithms. Four kinds of color gamut mapping algorithms multiply 8 test images are a set containing 32 kinds of combination, which presented to 13 observers in random order. At first, frequency distribution of scores for the 32 images by each observer corresponding to the combinations determined by the 4 kinds of algorithms and 8 test images is calculated, then the assessment scores, which are obtained by a data processing technique based on pairwise comparison methods, are converted to z scores for indication, with a 95% confidence interval. Four algorithms' average of z scores for all the source images and the observers are shown in Figure 5.

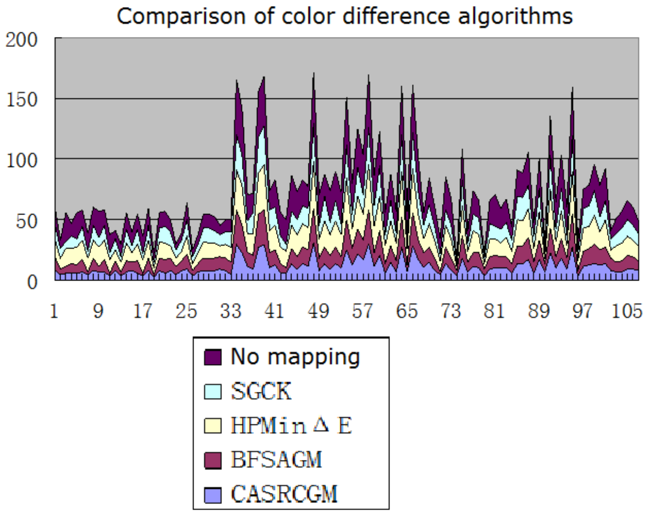

Figure 4. Comparison of color difference after mapping with different mapping algorithm

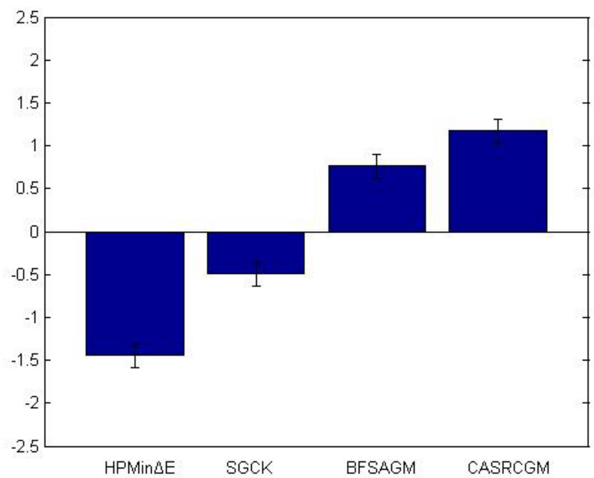

Figure 5. Four kinds of color gamut mapping algorithms compare the output obtained after gamut

Figure 5 shows that CASRCGM algorithm and BFSAGM algorithm are better than HPMinΔE algorithm and SGCK algorithm. It illustrates that spatial gamut mapping algorithm based on image can effectively enhance gamut mapping accuracy between digital image and device. But it is also found that in mapping process, CASRCGM algorithm is computationally more complex compared to HPMinΔE algorithm and SGCK algorithm.

Conclusion

This paper focus on approach and theory of color appearance model and spatial gamut mapping, a spatial gamut mapping algorithm framework suitable for the image-device is proposed, namely Color Appearance and Spatial Related Color Gamut Mapping (CASRCGM). Gamut mapping can be carried out with this algorithm using image color appearance attributes lightness (J), chroma (C) and hue angle (h) as mapping variables, image color appearance model (iCAM) as standard connection space, taking account of characteristics like color informations and color appearance attributes of each pixel perceived by human eye under different viewing conditions, by keeping the relative visual perception of each pixel from original image, then uniformity of color visual appearance for image color information after mapping can be achieved.

Mapping of 8 digital originals from the source image gamut to the target printer gamut, algorithms proposed in this paper and the HPMinΔE and SGCK algorithms recommended by CIE are compared respectively. Through design of output color patches and calculation of their color difference, and in monitor using a pairwise comparison method, mapped images were evaluated by psychophysical experiment. The results showed that the two proposed methods were better than HPMinΔE and SGCK in mapping precision and color appearance preservation, while more complicated and time consuming...

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References

[1] Li Xiao-zhou, Chen Guang-xue, Jia Chun-jiang, et al. Study on Influence of Filter Design Parameter on Printing Image Reproduction Quality in Spatial Color Gamut Mapping[A]. Shinri Sakai, Xavier Bruch. Technical Programs and Proceedings of NIP27[C]. USA: The Society for Imaging and Technology, 2011: 244-247

[2] Edgar Bernal, Robert P. Loce, Bala. Gamut Aim and Gamut Mapping Method for Spatially Varying Color Lookup Tables[P]. USA: 8077352B2, 2011

[3] Marius Pedersen, Jon Yngve Hardeberg. A New Spatial Hue Angle Metric for Perceptual Image Difference[A]. Lecture Notes in Computer Science[C]. France: Springer Verlag, 2009: 81-90

[4] Nicolas Bonnier. Contribution to Spatial Gamut Mapping Algorithms[D]. France: Telecom Paris Tech., 2008

[5] He Hua,Huan Hui,Sun Ya-ni et al. Study on Applicability of GOG Model for LCD Characterizing[J]. Journal of Kunming University, 2009, 31(3): 99-101

[6] Wang Yong, Xu Hai-song, Xu Dong-hui. Comparison study of display colorimetric characterization models[J]. Journal of Zhejiang University (Engineering Science), 2006, 40(6): 1085-1089

[7] Fabienne Dugay. Ivar Farup, Jon Y. Hardeberg. Perceptual Evaluation of Color Gamut Mapping Algorithms[J]. Color Research and Application, 2008:470-476

[8] Justin Laird, Remco Muijs, Jiangtao Kuang. Development and Evaluation of Gamut Extension Algorithms[J]. Color Research and Application, 2009, 34(6): 443-451

[9] Huang Qing-mei, Zhao Da-zun. An Evaluation Method for the Visual Effects of Different Gamut Mapping Algorithms[J]. Transactions of Beijing Institute o f Technology y, 2003, 23(4): 408-413

[10] Thurstone L.L. A Law of Comparative Judgment[J]. Psychological Review, 1927, 34: 273-286

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