Categorical Color Mapping for Gamut Mapping

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1 Abstract

New color mapping method that is useful for gamut mapping is introduced in this paper. This mapping method is named "Categorical Color Mapping" by authors, because it utilizes the categorical color naming to design color segmentation process. This paper shows concept and algorithm of the categorical color mapping and results of simulation regarding gamut mapping.

2 Introduction

An open color communication system needs gamut mapping technique to connect two devices that have different gamut each other. Indeed, it is almost impossible to find out devices that have same color gamut. Therefore, gamut mapping technique is essential to design a faithful color communication system.

Pair of points mapped between different devices is preferred to have the closest color appearance available. It is popular to choose the best strategy of gamut mapping by viewing many images which are produced according to various strategies, such as controlling hue, lightness ,chroma[1,2] and ATD[3]. Tip to get a good result is to test strategies as many as you can guess. Therefore, these methods might depend on experiential rules and need some cut-and-try processes.

On the other hand, the categorical color mapping has an obvious criterion to decide a mapping pair. The criterion is given simply by the categorical color naming and the maximum likelihood method.

3 Concept of Categorical Color Mapping

The Fig.1 shows a CRT (SONY GDM-2000TC) gamut and an ink-jet printer (EPSON PM-700C) gamut. Color temperature of white on the CRT is 9326K. Print papers are measured under D50. The difference of color gamut forces to make color appearance matching impossible throughout an image. Therefore, it is very important for gamut mapping strategy to earn the highest "likeness" in terms of color appearance between two devices. The point G_C is approximately the most saturated green on the CRT and the point G_P is also approximately the most saturated green on the print paper. Thus, the point G_C and G_P should be connected each other in order to make the likeness of the most saturated green the highest. Moreover, if these mapping manners are utilized throughout color space, the print image could have the closest color appearance for the CRT image. According to the above idea, the categorical color mapping estimates the likeness of color appearance to decide mapping pairs from the viewpoint of color categorical characteristics, and then the categorical color naming is utilized to estimate the likeness of color appearance.

Gamut mapping is also necessary to consider color adaptation, because a peek white, background condition and so on are usually different from each other. As shown in Fig.1, the white points(W_C and W_P) are located apart on CIE x-y coordinates. The categorical color mapping can link W_C and W_P under fixed viewing condition.

The categorical color mapping consists of "categorical segmentation" and "likeness comparison". The categorical segmentation divides a sender color space and a receiver one into nine segments respectively by utilizing the categorical color naming and the maximum likelihood method. The nine categories are gray, red, green, yellow, blue, purple, pink, orange and brown. This process is described in the next session in detail. On the other hand, the likeness comparison extracts a pair of points which gives the highest likeness from same categorical segment. This detail is shown in the 5th section.

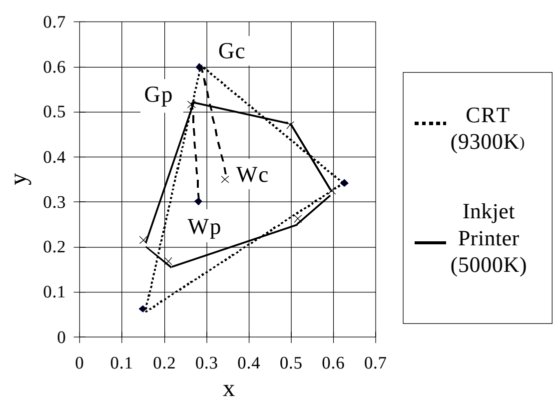

Fig.1 Gamut of CRT display and Inkjet

4 Categorical Segmentation

Kelly has investigated color categorical classification on CIE x-y coordinate as shown in Fig.2.[4] Also MacAdam has defined color discrimination characteristics by an ellipse as shown in Fig.3.[5] Based on their results, this paper assumes

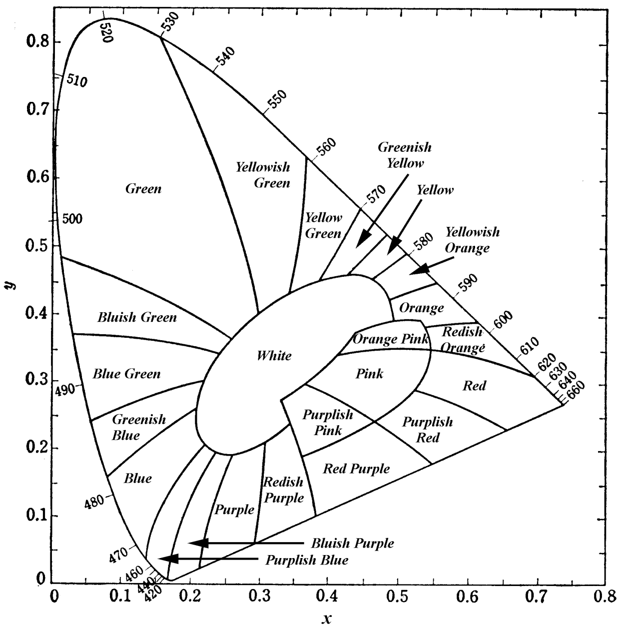

Fig.2 Kelly's color classification

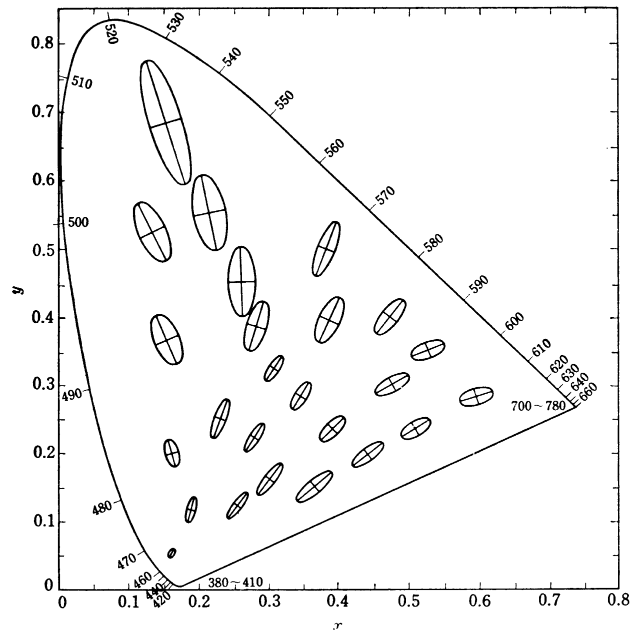

Fig.3 MacAdam's color discrimination ellipse

that a group of color category would form ellipse shape and a boundary line between different categories would be an intersection line between respective ellipses as illustrated in Fig.4. From the above point of view, each of segments are modeled by the 3D-Gaussian distribution.

A sender color space and a receiver one are divided into the nine color categorical segments by the maximum likelihood method. According to this method, a color vector $\mathbf{C}=[r\ g\ b]^t$ belongs a category which gives the minimum value to the eq. (1).

$$D^2 = \left(\mathbf{C}-\overline{\mathbf{C}}_i\right)^t \textstyle\sum_i^{-1}\left(\mathbf{C}-\overline{\mathbf{C}}_i\right) \qquad (1)$$

where

$$\overline{\mathbf{C}}_i = \left[\bar{r}_i \quad \bar{g}_i \quad \bar{b}_i\right]^t \qquad (2)$$

is average vector of category i (i= 0,1,2,…,8), Σ_i^{-1} is inverse matrix of varience-covarience matrix which is given by the following equation.

$$\Sigma_i^{-1} = \begin{bmatrix} \left(r-\bar{r}_i\right)^2 & \left(r-\bar{r}_i\right)\left(g-\bar{g}_i\right) & \left(b-\bar{b}_i\right)\left(r-\bar{r}_i\right) \\ \left(r-\bar{r}_i\right)\left(g-\bar{g}_i\right) & \left(g-\bar{g}_i\right)^2 & \left(g-\bar{g}_i\right)\left(b-\bar{b}_i\right) \\ \left(b-\bar{b}_i\right)\left(r-\bar{r}_i\right) & \left(g-\bar{g}_i\right)\left(b-\bar{b}_i\right) & \left(b-\bar{b}_i\right)^2 \end{bmatrix}^{-1} \qquad (3)$$

D^2 in the eq. (1) is called the Mahalanobis' distance. Symbol "r", "g" and "b" as element of color vector **C** is used as 3D color space coordinate for convenience's sake. It is acceptable that the color vector **C** consists of device dependent signals or colorimetric values.

The eq. (2) and (3) are defined by categorical color naming experiment. Test stimulus $\mathbf{T}_j = [r_j\ g_j\ b_j]^t$ (j = 0, 1, …, 854) is given to a CRT or an ink-jet printer as RGB drive level, and then an observer must answer color name of test stimulus on the CRT display or printed on paper by using the only nine color names, thus gray, red, green, yellow, blue, purple, pink, orange and brown. Test stimulus $\mathbf{T}_j$ are selected as generating answer for all nine color names in many times. The eq. (2) and (3) are calculated based on $\mathbf{T}_j$ classified into category i.

By the above procedures, the eq. (1) are defined for each nine categories and the arbitrary color space can be divided into nine segments by detecting the minimum value of D^2 for all nine categories.

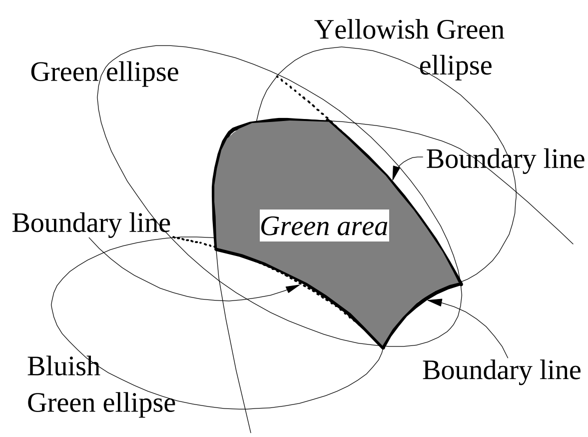

Fig.4 Relationship between Kelly's classification and MacAdam's ellipse

5 Likeness Comparison

After a sender color space and a receiver color space are divided into nine categorical segments, a mapping point is decided by the likeness ε which is defined as the following equation.

$$e = \frac{P_0}{V_0} \times \frac{P_1}{V_1} \times \cdots \times \frac{P_8}{V_8} \qquad (4)$$

$$P_i = \min(N_i \quad N'_i)$$

$$V_i = \max(N_i \quad N'_i)$$

where

$$N_i = \frac{\left|\overline{C_i}C\right|}{\left|\overline{C_i}O\right|} \qquad (5)$$

is called NSD(Normal Sender Distance),

$$N'_i = \frac{\left|\overline{C_i}Q'_m\right|}{\left|\overline{C_i}O\right|} \qquad (6)$$

is called NRD(Normal Receiver Distance) . The vector **O** and **O’** is called “Total Barycenter vector” and is given by the eq. (7) and eq. (8).

$$\mathbf{O} = \left[\frac{1}{9}\sum_{i=0}^{8}\overline{r_i} \quad \frac{1}{9}\sum_{i=0}^{8}\overline{g_i} \quad \frac{1}{9}\sum_{i=0}^{8}\overline{b_i} \right] \qquad (7)$$

$$\mathbf{O}' = \left[\frac{1}{9}\sum_{i=0}^{8}\overline{r'_i} \quad \frac{1}{9}\sum_{i=0}^{8}\overline{g'_i} \quad \frac{1}{9}\sum_{i=0}^{8}\overline{b'_i} \right] \qquad (8)$$

The total barycenter vector means an average vector among all nine barycenter vectors. The vector **Q’**$_m$ is a candidate color vector as a mapping point in a receiver color space. It belongs to the category **Q** that gives the minimum value for the eq. (1) among all nine categories in a sender color space. As illustrated in the Fig.5, the NSD corresponds to Mahalanobis’ distance between the input color vector and barycenter vector of category i(a dash line) normalized by Mahalanobis’ distance between the total barycenter vector and barycenter vector of category i(a solid line) in a sender color space. The NRD is given by same manner. In the case of the Fig.5, the number of categories is three for convenience’s sake.

The Fig.6 is a flowchart to decide the mapping point **C’** corresponding to the input color vector **C**. The Process[1] decides category **Q** to which sender color C belongs by detecting the minimum value of the eq. (1) among all nine categories. The Process[2] prepares candidate color vectors

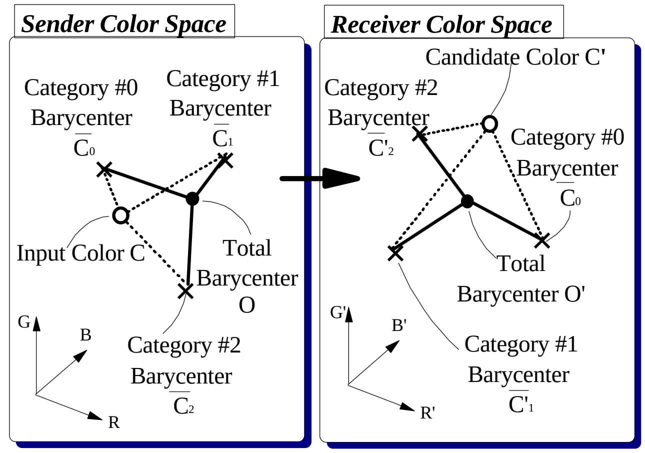

Fig.5 Graphical description of Likeness e

Q’$_m$ which classified into the category **Q** in a receiver color space. The Process[3] calculates the NSD according the eq. (5). The Process[4] also calculates the NRD according to the eq. (6). The Process[6] calculates the likeness ε according to the eq. (4) for all candidate color vectors Q’m(Process[5]) and detects the maximum value. A color vector that gives the maximum ε becomes the mapping point **C’**.

6 Simulations

6.1 Color Appearance Matching between 9300K CRT and 5000K CRT

Before to try gamut mapping simulation between a CRT display and a ink-jet printer, color appearance matching between 9300K CRT display (SONY GDM-2000GT) and 5000K CRT display(SONY GDM-2000GT) was tested by the categorical color mapping. It was checked that both CRT displays have almost same x-y coordinates of R, G and B primaries. So, this simulation is useful to test basic ability of mapping operation by checking color appearance matching between two CRT displays.

Portrait image (Fig.7) displayed on 5000K CRT is converted to match color appearance on 9300K CRT by the categorical color mapping. In short, 9300K CRT is a sender and 5000K CRT is a receiver. The matching target is the color appearance on 9300K CRT. The result of this test shown in the Fig.8(a) is not acceptable, because some pixels are strongly colored by unsuited hue(for instance, flesh tint is greenish). This result causes that the categorical segmentation is inaccurate as shown in the Table 1. In the Table 1, the *Correct* means that the categorical segmentation by the maximum likelihood method gives same answer as observer’s one. The *Wrong* means the opposite way. Unacceptable pixels almost belong to the *Wrong* group in a sender color space, and then the mapping point in a receiver color space is chosen from the *Wrong* category which does not have suited color vector to accomplish color appearance

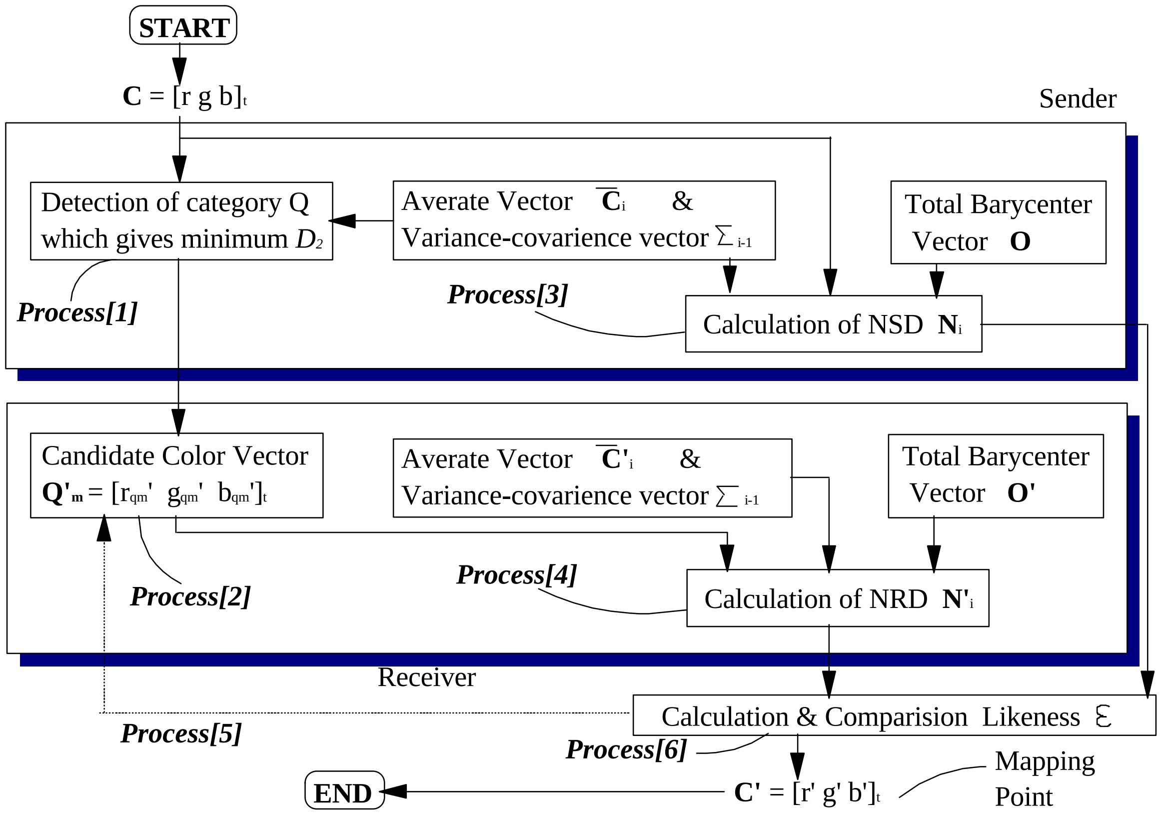

Fig.6 A flowchart to decide a mapping point corresponding to an input point by the categorical color mapping

Fig.7 Portrait image as an original image for simulation of the categorical color mapping (Original is color.)

Table 1 Accuracy of categorical segmentation by the maximum likelihood method for CRT displays

	Correct(%)	*Wrong(%)*
9300K	88	12
5000K	81	19

matching.

To solve the above problem, the candidate color vector **Q'**$_m$ is supplied from four categories which are selected in order of likeness . In short, the number of categories from which the candidate color vector **Q'**$_m$ is supplied alters one to four. To increase the number of the candidates recovers misjudgment of the categorical segmentation. This renewal method have been also tested by converting the portrait image of the Fig.7. By this simulation, it is conformed that the renewal mapping method has no problem regarding strongly colored error and keeps tone continuity well as shown in the Fig.8(b). Color appearance matching, however, is not exactly accomplished. The mapped image on 5000K is slightly different from the original image on 9300K.

The results of this simulation is summarized the

(a) The candidate color vector ***Q'***$_m$ *is supplied from one category.*

(b) The candidate color vector ***Q'***$_m$ *is supplied from four categories.*

Fig.8 The image which is converted to match appearance on 5000K CRT to on 9300K CRT (Original is color.)

followings.

- It is useful for recovering misjudgment of segmentation that the candidate color vector **Q'**$_m$ is supplied from four categories which are selected in order of likeness ε.
- To brush up accuracy of mapping, the definition of likeness should be improved by considering with human perception mechanism and mathematical operation.

6.2 Gamut mapping between CRT display and ink-jet printer

The categorical color mapping is applied to gamut mapping between 9300K CRT and ink-jet print (EPSON PM-700C) under 5000K lighting. Each gamut of them is shown in the Fig.1. This simulation includes difference of white color temperature and difference of color gamut. It corresponds to practical situation on the DTP(Desk Top Publishing). A sender is 9300K CRT and a receiver is ink-jet printer.

The image that is converted by the categorical color mapping is shown in the Fig.9. The results is summarized the followings.

- Tone continuity is kept sufficiently.
- All pixels are slightly colored green.
- Contrast is slightly down.

To solve the problems in terms of color balance and contrast, it would be useful to improve a control of dynamic range. The area A in the Fig.9 is printed by (R, G, B) = (50, 35, 35), in spite of the corresponding area in the original is (R, G, B) = (0, 0, 0). Therefore, contrast of printed image could be up by reducing printer drive level toward (R, G, B) = (0, 0, 0). Also, highlight area B in the Fig.9 is in same situation. The area B in the Fig.9 is printed by (R, G, B) = (234, 254, 226). Contrast of printed image could be up by raising the printer drive level toward (R, G, B) = (255, 255, 255). In short, it is important to control a dynamic range of printer drive level for preferred contrast reproduction. It is sure that matching of (R, G, B) between CRT drive level and printer one is not mandatory to establish a good gamut mapping. The present method to execute the categorical

Fig.9 The image which is converted to match appearance on printed paper under D50 to on 9300K CRT

color mapping is not enough to manage a dynamic range of a receive device.

A control of dynamic range would be also useful to keep color balance and white balance. Because no correspondence among R, G and B channel regarding a control of dynamic range causes to disturb color balance and white balance. It is sure that the other sources to destroy color/white balance had to lie. Dynamic range, however, is significant factor to effect color/white balance.

7 Conclusions

New color mapping method which is useful for gamut mapping have introduced in this paper. This mapping method is called "Categorical Color Mapping". It is unique that this mapping method has an obvious criterion to decide a mapping pair. The criterion is considered observer's color perception by utilizing the categorical color naming. Also, segmentation procedure applies 3D-Gaussian modeling based on Kelly's color classification and MacAdam's color discrimination ellipse.

Two simulations have estimated the ability of gamut mapping. One of them is color appearance matching between 9300K CRT and 5000K CRT. Another one is gamut mapping between 9300K CRT and print paper under D50 fluorescent light. By these simulations, possibility of the categorical color mapping to utilize gamut mapping is conformed. It shall be useful for improvement of the algorithm to control a dynamic range of device drive levels.

Moreover, two ideas will be tested to improve the current algorithm.

At first, a block average image which is given by replacing (R, G, B) values in subdivided area (such as 10 × 10 pixels) into average of these values will be utilized the categorical color naming experiment on behalf of simple color patches. This idea aims to improve the likeness of color appearance by focusing an only local color space in which a sender image exists. Moreover, preferred gamut mapping would depend on image contents. It is interesting that the block average image could contribute to add the image-contents-dependency to categorical color naming.

Secondly, RGB color space will be altered colorimetric space. This idea expects that the categorical color mapping is added universality by linking the CIE system. Conventional gamut mapping algorithm might depend on experiential rules and need some cut-and-try processes. On the other hand, categorical color mapping has an obvious criterion to decide a mapping pair. The categorical color naming and the maximum likelihood method decide the criterion simply. Therefore, if the CIE standard observer were taken the categorical color naming experiment, universal gamut mapping strategy could be established. Device dependent color space (such as RGB), however, also has advantages to omit procedure of colorimetric measurement and device characterization. This is very important for the low-end DTP systems.

As mentioned in the beginning of this paper, gamut mapping usually has to compensate difference of viewing condition among devices. So, gamut mapping strategy shall need to utilize the color appearance models. To analyze relationship between the categorical color mapping and the CIE TC1-34 would give some useful ideas to improve the current algorithm.

Acknowledgment

This research was supported by the Telecommunication Advancement Organization of Japan.

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