Color Reproduction Based on Low Dimensional Spectral Reflectance Using the Principal Component Analysis

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Abstract

Although, computer-controlled devices have been widely used, they have the problem of device-dependent color reproduction. As a rational solution for this problem, a color management system based on device-independent color space has attracted attention. However, such color management systems can only deal with images under standard illuminant because these systems are calculated by tristimulus values under standard illuminant, such as CIE XYZ or L*a*b*.

In this article, we propose to use spectral reflectances as the intermediate space for color management. We estimated spectral reflectance from pictures taken by a digital camera and displayed images on CRT appropriately.

Introduction

Lately, many kinds of computer-controlled color devices are used not only for business but also for personal use. But they have the problem of device-dependent color reproduction, that is, reproduced colors differ depending on each device.

As a rational solution for this problem, colorimetric color reproduction systems have been developped. They can convert color in both way from device dependent color values, such as CMYK and RGB, to the colorimetric values (CIE XYZ or L*a*b*) and the reve rse. However, such colorimetric color reproduction are characterized by both original and reproduced colors which have same CIE charackcies and illuminances, so we can only get the matched color under the defined illuminant. Therefore, we tried to construct the spectral color reproduction which was independent of illuminant.

In this article, we propose an illuminant independent color reproduction system which uses low dimensional spectral reflectances and a neural network. In the first part, we show reconstructions of spectral reflectances using small number of basis function s. The second part is about a color transformation method between device values and KL coefficients. We also present a device and illuminant independent color reproduction system.

Reconstruction of Spectral Reflectances with Small Number of Basis Functions

Measurement of Spectral Reflectances

To analyze wide variety of surface spectral reflectances, we measured many objects by a spectrophotometer (Photo Research SpectraScan PR-704). Some of them are manmade such as JIS color standard's color chips (1803 colors) and process printing CMY chart (1331 colors). The others are natural objects as follows: human skin of Japanese (10 men and 11 women), 34 leaves and 80 kinds of flowers in Japan. The spectral reflectances were sampled at 2-nm intervals from 380 to 780-nm (201 values). They were almost smooth in whole range.

Analysis

We tried to reduce the dimension of measured spectral reflectances using a principal component analysis (PCA), because the low dimensional spectral reflectances are very useful for personal computers.

A set of basis functions are calculated from spectral reflectances using PCA, and KL coefficients are calculated from each spectral reflectances using the functions. Both the functions and the coefficients can reconstruct spectral reflectances using the following linear model.

$$R(\lambda) = f(\lambda) + a_1\mu_1(\lambda) + a_2\mu_2(\lambda) + \dots + a_n\mu_n(\lambda)$$

$R(\lambda)$: Spectral reflectance
$f(\lambda)$: Average
$\mu_1(\lambda), \mu_2(\lambda), \dots, \mu_n(\lambda)$: Basis functions
$a_1, a_2, \dots, a_n$: KL coefficients

According to the reports by L. T. Maloney[1], J. L. Dannemiller[2] and J. K. Eem[3], they could reconstruct the spectral reflectances (10-nm intervals, between 400 and 700-nm, 31 values) with a small number of basis functions (3-4 functions) and their coefficients, so we analyzed spectral reflectances of the JIS charts and tried to reduce the dimension from 31 to 4. And we tried to reconstruct the spectral reflectances of many objects using common 4 basis functions which we re derived from JIS charts.

Figure 1 shows the common basis functions. To estimate the accuracy of this analysis, we calculated KL coefficients of all data sets, and reconstructed each data, using the basis functions. Figure 2 shows the reconstructions [(a)Human Skin, (b)Leaf]. Table 1 shows the color differences (Δ^*E_{ab}: D50, 2deg) between original spectral reflectances and reconstructions. The average color differences of every data set are lower than Δ^*E_{ab}=2.5. The values are too small for human vision to recognize the differences between original image and modified one. These results are silmilar to other studies. In addition, they show that the basis functions derived from JIS charts can be used for reco nstructing many kinds of objects.

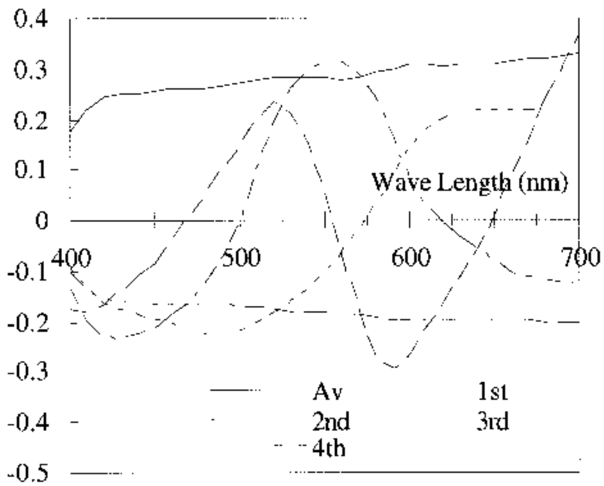

Figure 1. The common basis functions.

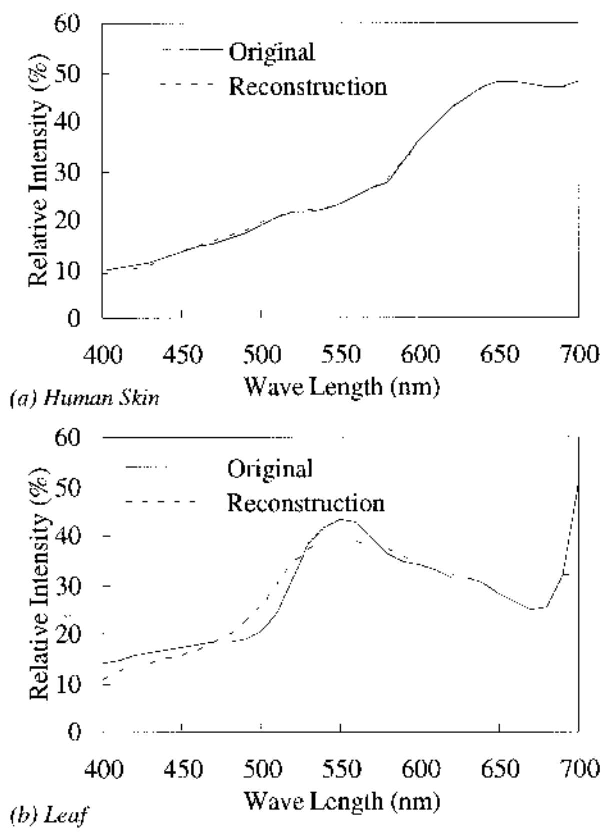

Figure 2. Original spectra and reconstruction

Table 1. Color differences ΔE^*_{ab} between original spectra and reconstructions.

	Maximum	Average
JIS Chart	9.63	1.01
CMY Chart	8.05	2.16
Human Skin	1.40	0.92
Flower	4.66	1.68
Leaf	5.22	2.50

Transformation Method using a Neural Network

The precious chapter shows the possibility for us to make a new color management system which uses spectral reflectances as the intermediate space. Secondly, we tried to make a transformation method from device values to KL coefficients. Usually, Look Up Table (LUT) method or Matrix conversion are used for transforming their color values. But we used a neural network for this non-linear transformation.

Figure 3 shows the structure of the network for estimating KL coefficients fr om RGB color values. The network includes 3 layers (Input layer : 3 units, Hidden layer : 15 units, Output layer : 4 units). For the input data, we used 4 sets of RGB values which were derived from the pictures of the JIS charts taken by a digital camera (Kodak DCS420) under the following light conditions: Day Light (Noon), Day Light (Evening), Day Light Lamp, Tungsten Lamp. As the teaching data, we used a set of KL coefficients. We trained the network with the Back Propagation algorithm.

The accuracy of each network was more than 98.5%. It shows that the neural network is useful for infering KL coefficients (spectral reflectances) from RGB values.

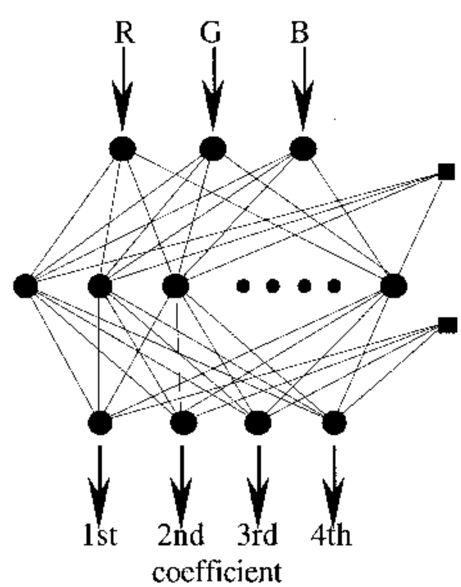

Figure 3. Structure of the neural network.

Proposal – Color Reproduction Method

We have been able to calculate spectral reflectances from input device values (RGB), so we present the illuminant and device independent color reproduction system. In this paper, we show the method to display the reproduced images on a CRT monitor. Figure 4 shows the flow of the data transformation system.

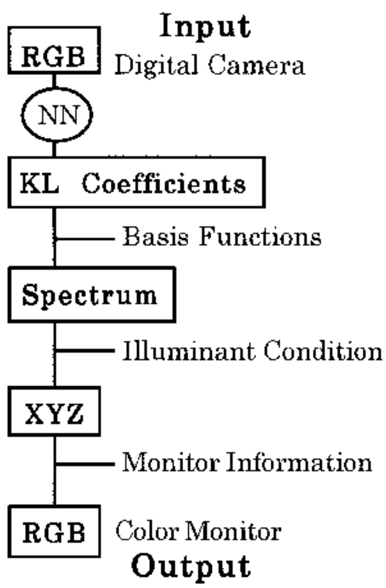

Figure 4. Flow of the transformation.

Table 2. Color differences ΔE^*_{ab} between the original colors and reproduced ones.

		Non-Trans	Proposal
Daylight	Max	85.99	29.50
(noon)	Av	42.09	4.74
Day Light	Max	105.23	67.38
(Evening)	Av	35/10	8/38
DayLight	Max	83.98	31.86
Lamp	Av	35.47	4.67
Tungsten	Max	108.23	51.43
Lamp	Av	48.13	5.93

In this system, at first , we get the CIE XYZ values using infered spectral reflectance from RGB color values and observed illuminant values. After that, the reproduced RGB color image is calculated by the matrix which includes phosphor values and gamma values of the monitor. In this experiment, we used a calibrated color monitor (SONY GDM-2000TC) for output device.

We estimated this system using the JIS charts. Table 2 shows color differences (Δ^*E_{ab}) between the original color set and the reproduced color using proposal method or non-transformed color. The average color differences between the original set and non-transformed one were about $\Delta^*E_{ab} = 40$. And the average ones between the original set and transformed set were about $\Delta^*E_{ab} = 5$. The color difference ($\Delta^*E_{ab} = 5$) will not be visually noticeable in color images.

Figure 5 shows the accuracy of non-transformed reproduction and the proposal one plotting on a*b* plane of CIE L*a*b* color space. We can see that the proposal system performs a high accuracy color reproduction, especially, the chroma area was spread widely.

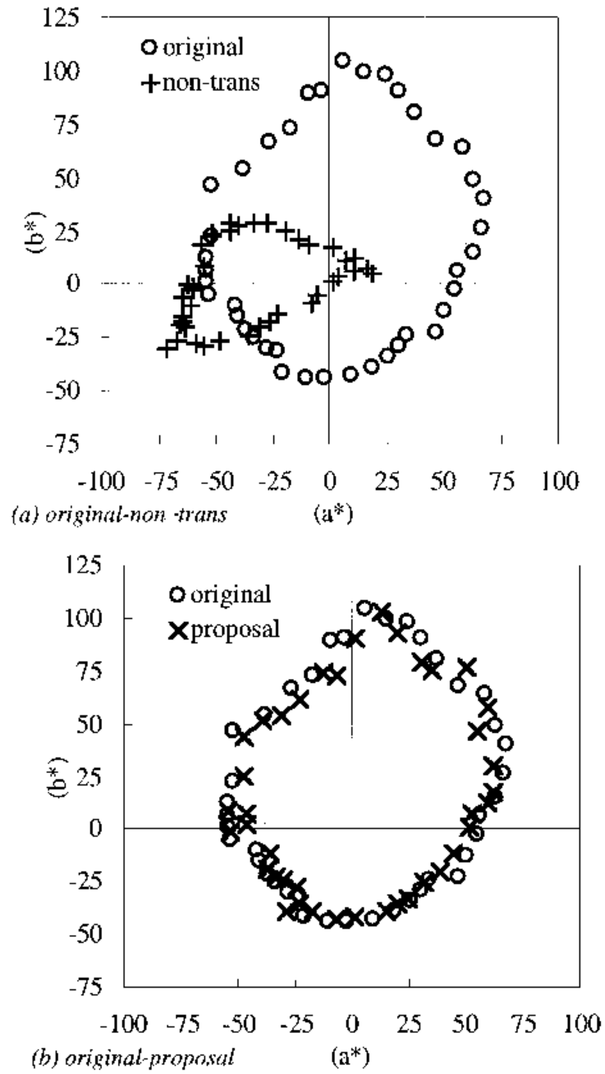

Figure 5. Accuracy of the proposed method.

Conclusion

We reduced the dimension of surface spectral reflectances from 31 to 4 by using a principal component analysis. The average color difference (D50, 2deg) between original spectral reflectances and reconstructions using common 4 basis functions was lower than $\Delta^*E_{ab} = 2.5$ for any kinds of objects.

We converted the device values (RGB) to KL coefficients by using the neural network. The accurcy of network was more than 98.5%.

We displayed reproduced images on a CRT monitor. The average color difference between original images and reproductions was about $\Delta^*E_{ab} = 5$.

Our proposal system shows the possibility of illuminant and device independent color reproduction.

References

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