RGB to Multi-Spectral Image Conversion By Spectral Palette and Color Print Simulation Under Different Illuminants

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Abstract

A simple idea of RGB to spectral image conversion is proposed. A spectral reflectance with the closest colorimetric value to that of RGB pixel is picked up from the spectral color palette and embedded in each pixel of RGB image. SVD (Singular Value Decomposition) is applied to compress the high-resolution spectral image.

Spectral image data are rearranged to *36 pixels* × *36 spectra* sub-block so that we could make use of strong correlations in both spatial and spectral. The spectral image could be very well reproduced from a small number of singular values by SVD. Although a transformed image has not the real world spectra but palette-based pseudo-spectra, the proposed method could be applied to simulate the color appearances for a given set of ink and paper media under the different illuminants, and to estimate how much the huge spectral image data could be compressed. The paper discusses the color reproducibility by SVD compression and introduces the estimated color appearances for inkjet prints under the different fluorescent lamps.

1. Introduction

A multi-spectral image carries the raw color information essential for estimating color under different illuminants.

A variety of multi-spectral image capture schemes[1-4] have been proposed. It needs expensive and slow measurements to catch the spectral images with high spectral and spatial resolutions. Since spectral information of natural objects is widely applied for remote sensing, printing, medical, or artistic imaging, alternative technologies for preserving the spectral data are much interested. Estimation of reflectance spectra from reduced low-dimensions has been attempted to approach this requirement.[5-10] K-L transform or PCA provided a mathematical solution to this problem. However, these methods still need multi-band sensors more than three. This paper proposes a simple but novel method to transform the conventional RGB tri-color images into spectral images with high spatial and spectral resolutions, where the RGB pixel is replaced by the closest spectral chip in palette.[11] Each spectral chip is composed of spectral reflectance in 380-730 nm by 10 nm step. Although the transformed spectral image is not from the real world scene but carries the precise actual spectra just as painted by real palette media such as ink and paper. Because the created spectral image is highly correlated both spatially and spectrally, it is compressed by employing Singular Value Decomposition (SVD). Finally the restored spectral image from compressed SVD data is applied for the color appearance simulation on inkjet print under the different illuminants.

2. Embedding Spectrum in RGB Pixel

Figure 1 shows the overview of proposed system. First, a RGB or XYZ tri-color image is transformed into L*a*b* image and a spectral palette corresponding to the L*a*b* values is generated as the LUT. Each pixel in source image is replaced by the spectral chip with L*a*b* value closest to that of pixel. That is, the spectrum k is embedded in pixel i by choosing the chip $j=k$ to minimize the color difference between the pixel i and spectral chips $j=1,2,\ldots, J$ as follows.

$$\Delta E^*_{ik} = \min_{j=1}^{J}\left\{\Delta E^*_{ij}\right\} = \min_{j=1}^{J}\left\{\left\| LAB_{PIX(i)} - LAB_{SPECT(j)} \right\|\right\} \quad (1)$$

For example, RGB image with $K \times L$ pixels is converted into the spectral image with $KL \times 36$ channels.

To create the high precision spectral images, sufficient number of spectral chips is necessary, but it is difficult to measure the huge number of full color chips. So, the measured spectral pallets data are interpolated in practice.

A test image in Fig. 2 (a) with the color distribution in (b) was converted into spectral image (d), by looking up the inkjet spectral palette in (c). The image (d) was created by directly looking up the closest spectrum from the 1331 basic inkjet spectral palette. The replaced color pixels obviously lack the gray levels because of insufficient number of spectral chips in palette.

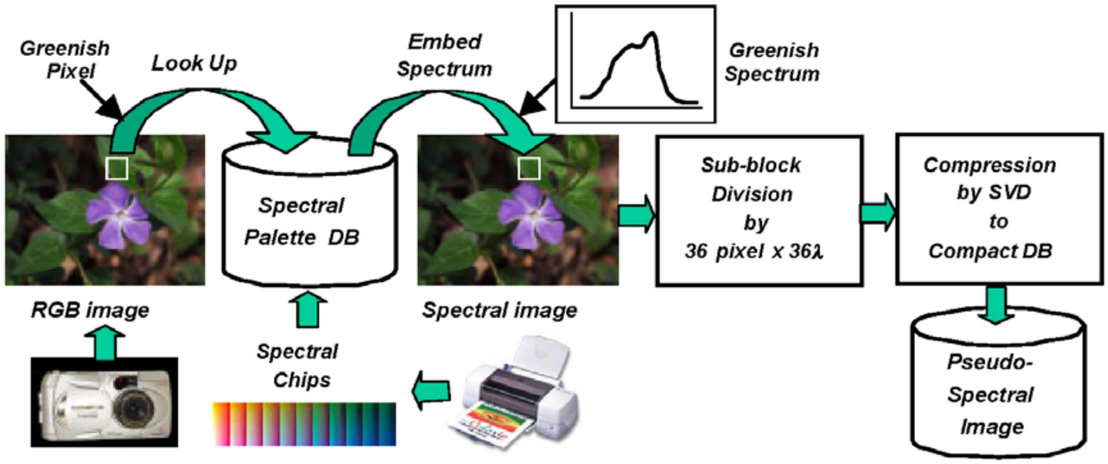


Figure 1. Overview of RGB to Spectral Image Conversion System using Spectral Palette

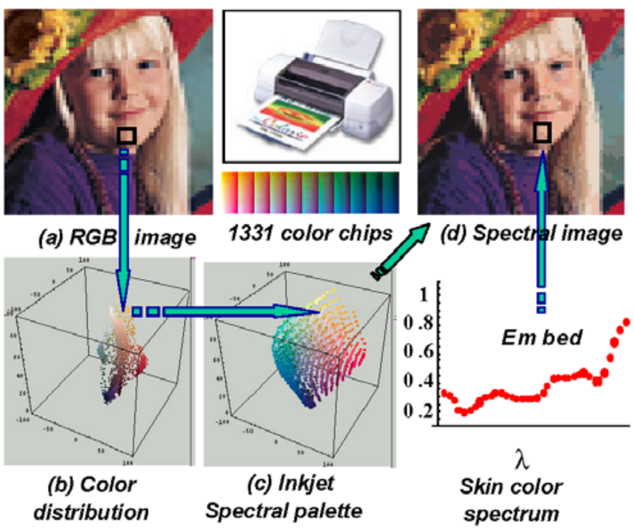


Figure 2. Spectral image conversion by inkjet palette

3 Interpolation of Spectral Color Palette

A basic spectral color pallet was created by measuring the spectral reflectance for N=11^3=1331 CMY color chips printed by Epson PMC800 inkjet printer on coated paper. Each color chip carries 36 spectra in 380~730 nm by 10 nm step. The lack of chips in palette causes undesirable artifacts in tonal reproduction. This problem is solved by increasing the printed number of chips or by spectral interpolation. Figure 3 illustrates a basic idea of spectral interpolation. A linear spectral interpolation between i-th and (i+1)-th spectral chips makes the new intermediate chip as follows. Letting the multi-spectral vector of j-th chip be

$$\boldsymbol{C}_j = [C_j(\lambda_1), C_j(\lambda_2), \cdots\cdots, C_j(\lambda_{36})]^t \tag{2}$$

The intermediate spectrum $\boldsymbol{C}_j(d)$ at distance ratio d from $\boldsymbol{C}_j$ and (1-d) from $\boldsymbol{C}_{j+1}$ is calculated by

$$\boldsymbol{C}_j(d) = (1-d)\boldsymbol{C}_j + d\boldsymbol{C}_{j+1} \tag{3}$$

If the spectral interval between $\boldsymbol{C}_j$ and $\boldsymbol{C}_{j+1}$ is divided by K (K is integer) discrete steps, the distance ratio d and new chip number jk at k-th position are given by

$$\begin{aligned} d &= (k-1)/K \\ jk &= K(j-1)+k \quad for \;\; k = 1 \sim K \end{aligned} \tag{4}$$

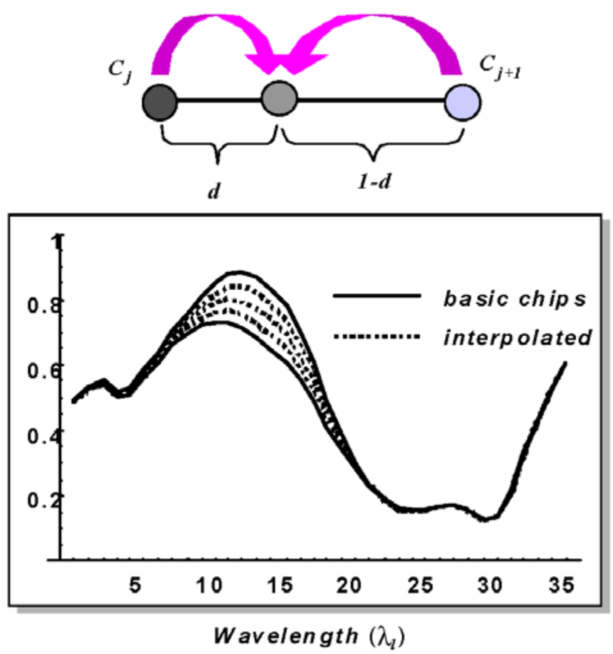


Figure 3. Spectral interpolation

Denoting the interpolated vector be $\boldsymbol{C}_{jk}$ for $\boldsymbol{C}_j(d)$, each spectral element of new vector $\boldsymbol{C}_{jk}$ is calculated by

$$\begin{aligned} \boldsymbol{C}_{jk} &= [C_{jk}(\lambda_l)]^t \quad ; l = 1 \sim 36 \\ C_{jk}(\lambda_l) &= (1 - k/K + l/K)C_j(\lambda_l) + (k/K - l/K)C_{j+1}(\lambda_l) \end{aligned} \tag{5}$$

Thus $j=1 \sim J$ colors chips are increased to J_{int} as

$$J_{int} = K(J-1)+1 \tag{6}$$

Figure 4 shows an example of spectral images created by embedding the interpolated spectra in RGB image (a). Here (b), (c), and (d) show the converted images by $J=1331$ basic pallet, $J_{int}=5331 (K=4)$ and $J_{int}=10641 (K=8)$. Interpolated palettes. (e), (f), and (g) show the color distributions of the corresponding palettes in CIELAB space. The images shown in (c) and (d) are clearly improved in the gradation as compared with (a).

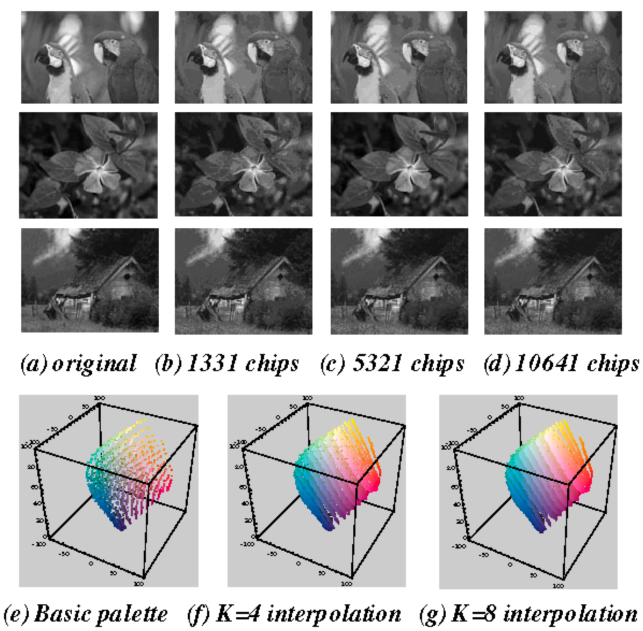


Figure 4. Gradation improvement by spectral interpolation

4. Sub-Block Replacement of Spectra

Because the converted spectral image has 12 times much data in comparison with original, the data is desirable to be compressed. In order to make use of spatial and spectral correlations, the source image was divided into sub-blocks by 6 x 6 pixels and each sub-block was rearranged into 2D array of 36 spectra × 36 pixels in Fig. 5. The rearranged spectral block is strongly correlated spatially and spectrally.

5. Compression of Spectral Image by SVD

The rearranged sub-block image is compressed by removing the redundancies based on ***SVD***. The matrix data in sub-block (*m, n*) is represented by

$$\begin{aligned} \boldsymbol{R}_{mn} &= \left[r_{ij} \right]_{mn} \quad ; i, j = 1, 2, \cdots, 36 \\ &\qquad ; m = 1, 2, \cdots, M, \; n = 1, 2, \cdots, N \end{aligned} \tag{7}$$

where, r_{ij} denotes a spectral reflectance of i-th pixel at j-th wavelength: $\lambda=380+10(j-1)$ nm. M and N are the block numbers in row and column of sub-blocks.

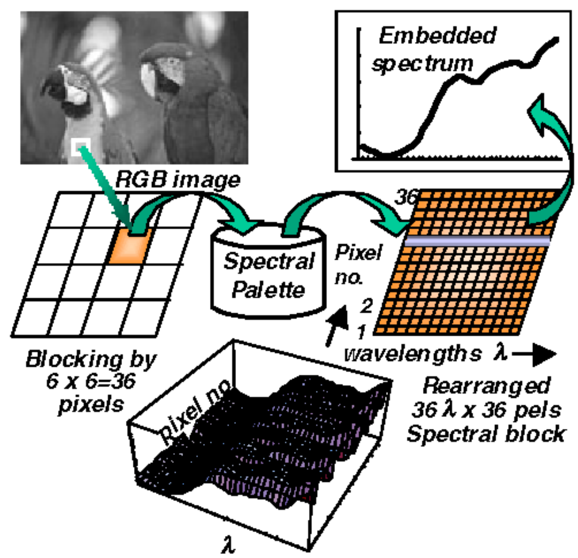


Figure 5. Blocking and rearrangement of spectral image data

The local spectral image $\boldsymbol{R}_{mn}$ in mn-th sub-block can be expressed by SVD as

$$\boldsymbol{R}_{mn} = \left[r_{ij} \right]_{mn} = \boldsymbol{U}_{mn} \Lambda_{mn} \boldsymbol{V}_{mn}^t \tag{8}$$

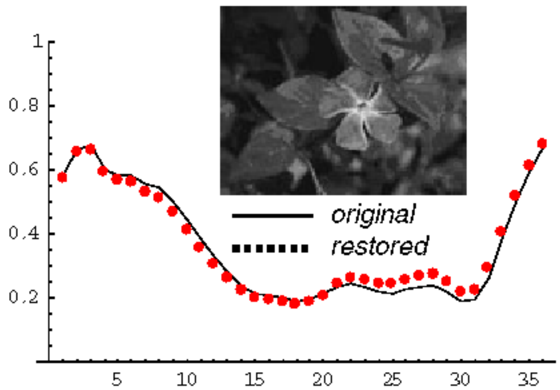
where, the columns of $\boldsymbol{U}_{mn}$ and $\boldsymbol{V}_{mn}$ are the eigenvectors of $\boldsymbol{R}_{mn}\boldsymbol{R}_{mn}^t$ and $\boldsymbol{R}_{mn}^t\boldsymbol{R}_{mn}$, and Λ_{mn} is 36 x 36 diagonal matrix containing the singular values of $\boldsymbol{R}_{mn}$ along its diagonal. Because $\boldsymbol{U}$ and $\boldsymbol{V}$ are orthogonal,

$$\Lambda_{mn} = \boldsymbol{U}_{mn}{}^t \boldsymbol{R}_{mn} \boldsymbol{V}_{mn} = \begin{bmatrix} \lambda_1 & 0 & \cdots\cdots & 0 \\ 0 & \lambda_2 & 0 \cdots\cdots & 0 \\ \vdots & & & \vdots \\ \vdots & & \ddots & \vdots \\ 0 & \cdots\cdots & 0 & \lambda_{36} \end{bmatrix} \tag{9}$$

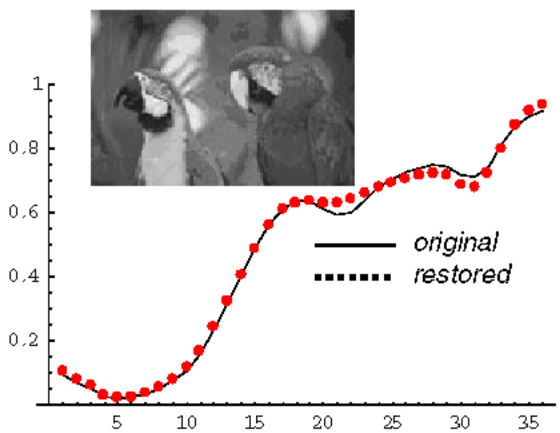
Here, a sub-block image $\boldsymbol{R}_{mn}$ is approximated by

$$\hat{\boldsymbol{R}}_{mn} \cong \hat{\boldsymbol{U}}_{mn}\hat{\Lambda}_{mn}\hat{\boldsymbol{V}}_{mn}{}^{t} \tag{10}$$

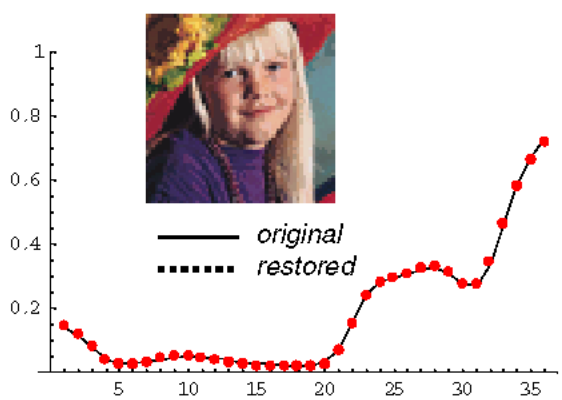
That is, the 36 × 36 matrix $\boldsymbol{R}_{mn}$ can be restored from the small number of S (< 36) singular values $\hat{\Lambda}_{mn}$ with ($\lambda_1 \sim \lambda_S$) and the eigen vectors of 36×S $\hat{\boldsymbol{U}}_{mn}$ and S×36 $\hat{\boldsymbol{V}}_{mn}$ matrices.



(a) Purple petal in center



(c) Yellow neck in lower left parrot



(b) Red hat in top right

Figure 6. Restored reflectance from only two SVD parameters (S=2)

6. Experimental Results

6.1 Reconstruction from Compressed SVD Image

The spectral image was compressed using small number of ***SVD*** parameters and reconstructed. Figure 6 (a)~(d) show the reproduced spectral reflectance from only two singular values λ_1 and λ_2 with corresponding eigen vectors. The dotted plots show the reproduction in 36 wavelengths as compared with the original solid line. The complex spectral reflectance is almost well reconstructed in detail. The *rms* color difference was around $\Delta E^*_{ab} \cong 5$ or less for $S \cong 2 \sim 3$.

6.2 Print Image Estimation Under the Different Illuminants

The proposed method enables to simulate the appearance of color prints under the various illuminants as if printed with the same set of ink and paper used in palette without any expensive spectral camera. Figure 7 shows an example of predicted color reproductions under the four different fluorescent lamps. The spectral image was converted from sRGB image using Epson color inkjet spectral palette.

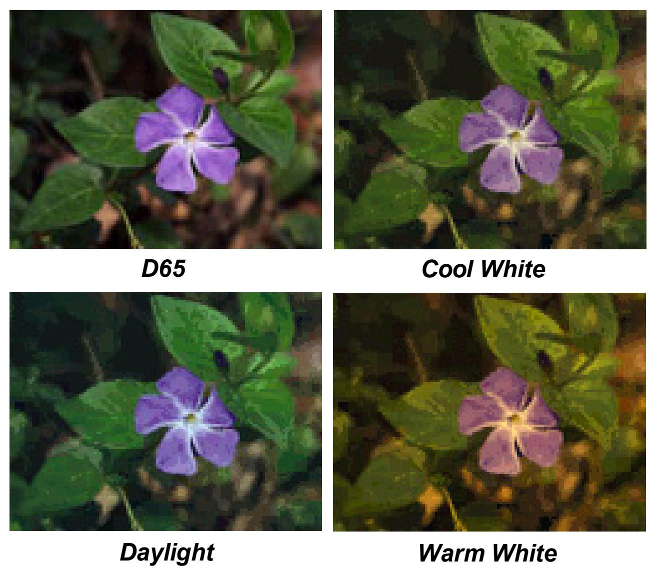


Figure 7. Inkjet color appearances under typical fluorescent lamps.

7. Discussions and Conclusions

An idea for embedding the spectral pallet in RGB pixels was proposed. SVD was useful to compress the local spectral sub-block image rearranged in 36 pixels × 36 spectra by making use of strong correlations in both spatial and spectral. As a result, the multi-spectral image was restored from a few singular values in accurate. Although a created image has not the real world spectra but pallet-based pseudo-spectra, the proposed method is applied to simulate the color appearances for different ink and paper sets under the various illuminants and to estimate how much the huge spectral image data could be compressed. Since the number of spectral chips is not enough, spectral interpolation could help to embed them in full-color RGB image. The reliability in linear spectral interpolation for limited number of spectral chips made by color ink sets or other materials should be evaluated in future works.

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Biography

Hiroaki Kotera received his B.S degree from Nagoya Institute of Technology and Doctorate from University of Tokyo. He joined Matsushita Electric Industrial Co in 1963. Since 1973, he has been working in digital color image processing at Matsushita Research Institute Tokyo, Inc. In 1996, he moved to Chiba University. He is a professor at Dept of Information and Image Sciences. He received Johann Gutenberg prize from SID in 1995 and journal awards from IS&T in 1993, from IIEEJ in 1990 and 2000.