

A New Color Management System Based on Human Perception and its Application to Recording and Reproduction of Art Paintings

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Abstract

A new color management system has been developed for high definition color recording and reproduction of art paintings. This system is consisted of high accurate multi-band camera, personal computer and projected type display. The multi-band camera is composed by five band filters and single chip CCD camera with 2048x2048 pixels. The reflectance spectra of each pixel of the object were estimated by using five band images within less than the average color difference $\Delta E^*ab = 1.16$. The spectral transmittance of five filters was determined by simulated annealing method and principal component analysis of spectral reflectance of paintings. Images of art paintings were reproduced onto the projection type monitor under the consideration of color appearance. In this paper, we describe methods to estimate of reflectance spectra of paintings from five band images, optimization of spectral transmittance of filters and color reproduction of paintings based on the color appearance models.

Introduction

In recent years, high accuracy digital color imaging system is required in artworks and medical imagings by the advent of information superhighway. In artworks, conventional photographic system has been used for image acquisition and recording. HDTV(High Definition Television) are also used for displaying the paintings, arts and crafts in several Japanese museums. Photographic system, hybrid imaging system used film and scanner, and HDTV system only record the R,G,B three channel images, and they cannot record the reflection spectra of the objects. Reflection spectra is one of the most important information of the objects, and it is not dependent on the spectral radiant distribution of the taking light source. On the other hand, color reproduction of those imaging systems is based on the colorimetric color reproduction as to have same chromaticities between object and image. However, it should be considered the color reproduction based on the human perception such as color adaptation under the viewing condition in an art gallery or museum. We have developed the high accurate imaging systems which is consisted of image acquisition system used multiband CCD camera, color management system based on color adaptation model and estimation of reflection spectra of the objects, and display systems as shown in Figure 1. In the following sections, detail of the developed imaging systems is described.

Multiband camera and the Estimation of Reflection Spectra

In image acquisition, we used two high quality digital cameras; Fotex F-10 (2048x2048 pixels, 12 bits/pixel) and Kodak DCS420m (1536x1024 pixels 12bits A/D, 8 bits output). Multiband images were captured by digital camera incorporating a rotating wheel comprising five color filters in front of camera lens. Gray scales with 16 steps and crop marks were recorded with object in each channel, and each channel image data was merged into single file.

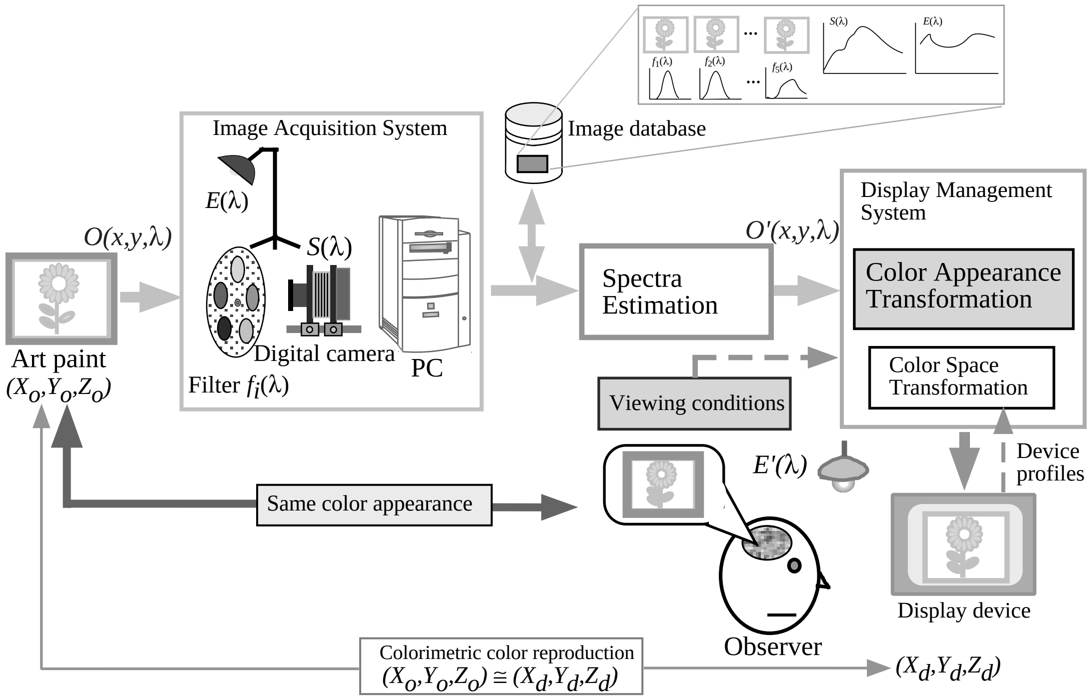

Figure 1. Schematic diagram of proposed color management system.

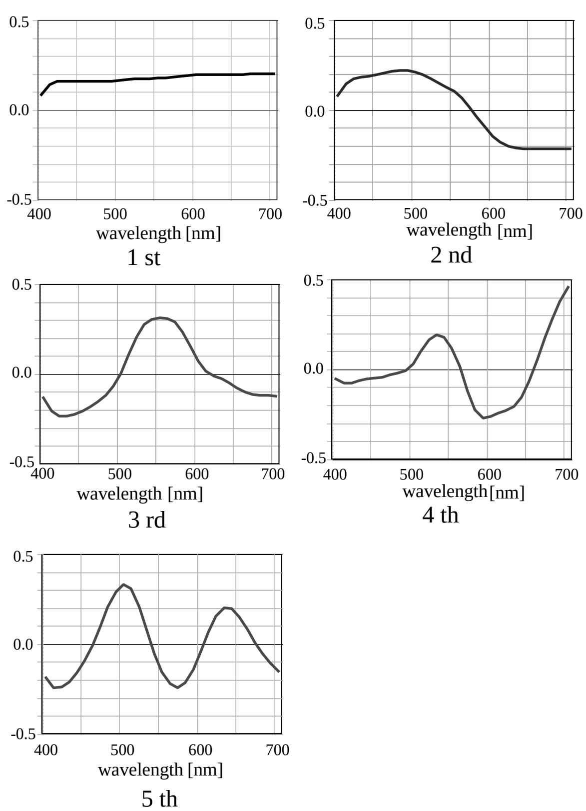

Figure 2. Principal components of reflection spectra of 147 oil paint samples.

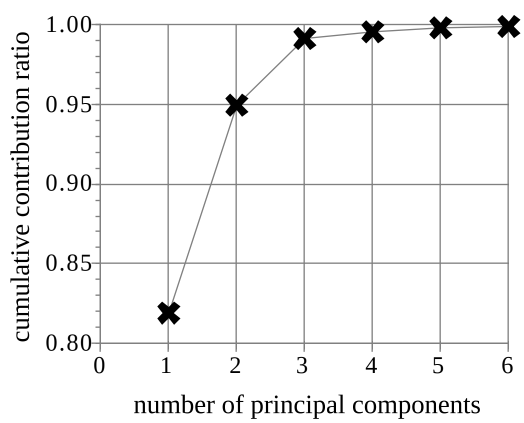

Figure 3. Cumulative contribution ratio of principal components.

Reflectance spectra of several thousands color patches and oil paintings were measured in order to decide a number of filters for taking multiband images. Those measured reflectance spectra were analyzed by principal component analysis. Figure 2 shows five major principal components. Figure 3 shows cumulative contribution ratios of these principal components. The results show the spectral reflectance of the paintings can be estimated 99% by using a linear combination of five principal components. From this experimental result, we decided to use five bands to record the spectral reflectance of the object. On the other hand, spectral reflectance of the object can be also estimated by Wiener estimation method as shown in a previous paper[1]. In our color management system, reflection spectra of the objects were estimated by those two methods.

Designing of Separation Filter

In the Wiener estimation method, the accuracy of the estimation of reflection spectra is mainly dependent on the spectral transmittance of separation filters. Then we determined the spectral transmittance of the separation filters by using simulated annealing method. Considering the practical designing of filters, we assumed that the spectral transmittance of five filters has Gaussian type as follow,

$$f_i(\lambda) = \exp\left[-\frac{(\lambda-\lambda_{ci})^2}{\sigma_i^{\,2}}\right] \quad (\text{ i }=1,2, ..., 5 \text{ }) \qquad (1)$$

where λ_c is a peak wavelength and σ_i is a half-band width.

Characteristics of Gaussian type filters can be determined by peak wavelength and half-band width, both parameters of filter was optimized by using the simulated annealing method. In this nonlinear optimization method, as a cost function, the Euclid distance (or the color difference in $L^*a^*b^*$ color space) between actual and estimated spectra was used. Figure 4 shows the schematic diagram of filter optimizing process. Figure 5 shows the spectral transmittance of five filters obtained by optimization method. Figure 6 shows the color difference between original and estimated reflectance spectra of 147 oil paintings.

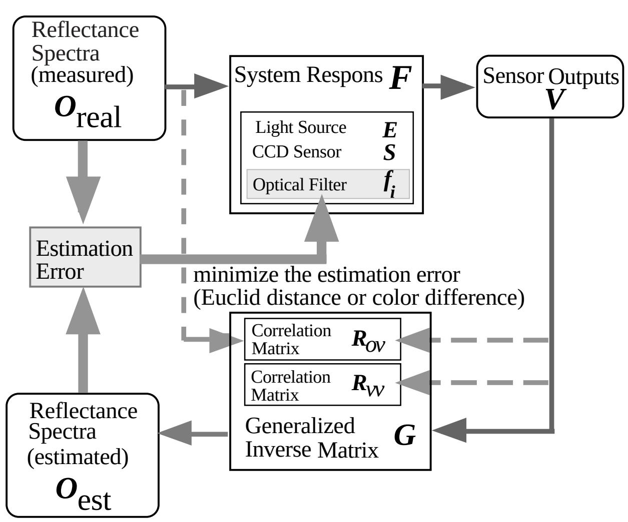

Figure 4. Schematic diagram of filter optimization by using Wiener estimation method.

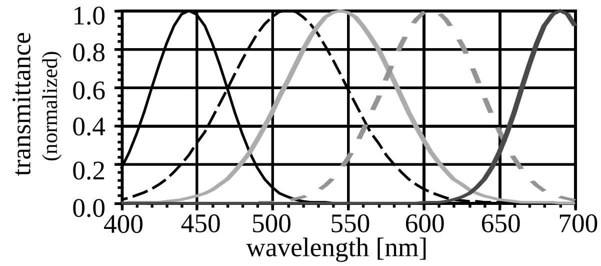

Figure 5. Spectral transmittances of optimal filter set.

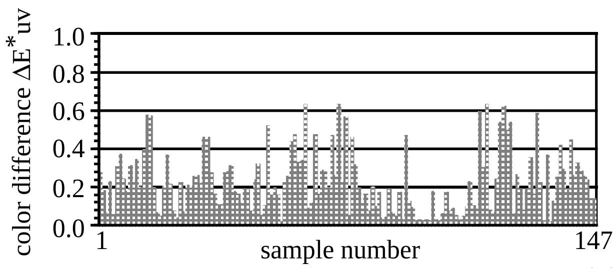

Figure 6. Estimation errors(color differences in CIE $L^*u^*v^*$).

Characteristics of optimum filter transmittance could be determined, however, it is not easy and it is expensive to make such filters in practice. Then, optimum combination of five filters to minimize the color difference were determined from 24 kinds of gelatin filter set, namely 42,504 combinations of filter, by computer simulation. Figure 7 shows the spectral transmittance of five filters selected by computer simulation and these filter sets were used to take practical multiband images.

[Experimental settings]

Filter Set: FUJI FILM OPTICAL filter (TAC base)
bandpass [BPB-42,45,50,53,55,60,BPN-53]
sharp cut [SC-58,60,64,66,68]
separation [SP-1,2,3,5,6,7,9,10,11,15,17,19]
Light Source : CIE D65
$\Delta\lambda$: 5nm [380 - 780 nm]
Cost Function : Euclid distance between actual and estimated spectra

Results : [SP-1, SP-7, SP-15, SC-60, SC-68]
average color difference $\Delta E^*ab = 1.16$

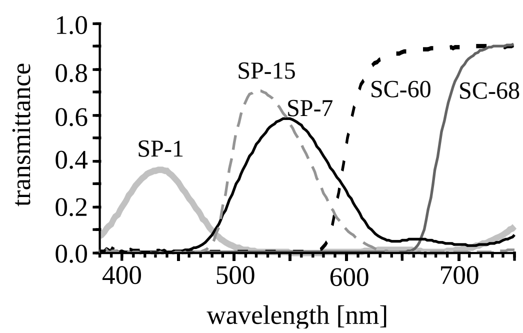

Figure 7. Optimal filter combination(actual filter set).

Color Reproduction and Display

Almost color management system for device independent color reproduction is based on the colorimetric color reproduction. However, the perceived colors are different from colorimetric color. Mechanism of human perception and perceived color are very complex. In our color management system, we introduced color adaptation under the different illuminant for color reproduction and display as most simple case. Several color adaptation models have been proposed by von Kriess, Hunt, Fairchild[2,3] etc. These models, however, are based on color matching experiment of the color patches. In a previous paper[4,5], we reported that these models are not always applied to predict the color of face and paintings. Then, we proposed modified Fairchild model for prediction of color of facial pattern. In our color management system, this model was introduced to predict of paintings color under the different viewing illuminant. Figure 8 shows the color appearance transformation process of our display management system.

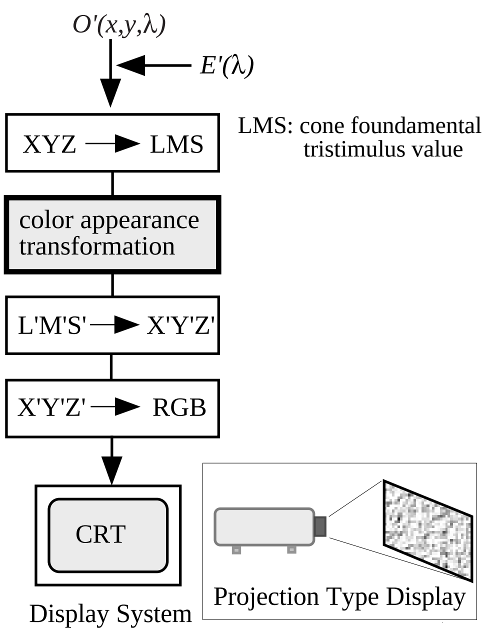

Figure 8. Schematic diagram of our color appearance transformation process.

As shown, reflection spectra of the sample $O(x,y,\lambda)$ is firstly estimated by using the five band images. Secondly, from the tristimulus values XYZ of the sample under the illuminant $E'(\lambda)$, the retinal cone responses after adaptation L'M'S' is estimated by using modified Fairchild color adaptation model, and the tristimulus values X'Y'Z' after adaptation is obtained by linear transformation. Thus, RGB signal values to CRT or projection type monitor can be derived from X'Y'Z'.

Conclusion

We have developed high accurate digital color imaging system consisted of multiband CCD camera and projected type CRT based on a new color management system for art paintings. The spectral reflectance of the paintings could be estimated within less than $\Delta E^*ab = 1.16$ by using our filter optimizing method. It also became possible to reproduce the image of paintings under the consideration of color adaptation.

Acknowledgments

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