Proposals of Standard Spectral Image and its Application to Designing of CCD Camera

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Abstract

We have developed a five-band CCD camera with 3120(H) and 2160(V) pixels and 16 bits dynamic range for recording the reflectance spectra of the object for digital archives. In the previous papers,[1,2,4] we applied those developed systems to record the reflectance spectra of paintings and other artifacts.

In this paper, we introduce the standard spectral images taken by developed multi-spectral imaging systems. Eight kinds of object, (1) **Chart**, (2) **Oil paint**, (3) **Japanese paint**, (4) **Object at rest**, (5) **Fruits**, (6) **Bottle**, (7**) Portrait**, (8) **Wool** were taken by using developed five-band camera. Sample program to estimate the reflection spectra of the object used Wiener estimation method and principal component analysis are also presented with same database. Those standard images were used to designing the optimum spectral transmittance of color filter for single chip CCD camera.

Introduction

In recent years, high accuracy digital color imaging systems have been required in artworks, e-commerce, medical imaging and others instead of conventional photographic film systems. Therefore, CCD cameras have been developed and widely used, however, normal CCD camera cannot record the spectral reflectance of the object since CCD cameras has only three channel devices generating RGB signals. RGB or CIE-XYZ tri-stimulus values are dependent on the spectral characteristics of imaging devices and illuminant conditions. Therefore it is necessary to record the true reflectance spectra of the object for high accurately device independent color reproduction and computer simulation for designing in image capturing systems.

In a previous paper, we introduced a multi-band camera system for recording reflectance spectra of the object for digital archives and electronic museum. In this paper, we propose eight kinds of standard image with reflectance spectra of the object taken by developed multi-band camera systems. Many standard color images based on RGB, CMYK or tri-stimulus values such as SCID Data base have been proposed and widely used for evaluation of color reproduction and image quality for printing systems, however, those are not able to use the designing of the spectral sensitivity of capturing systems since those have not spectral reflectance of the object. In this paper, we propose eight kinds of standard image with reflectance spectra of the object and those images are applied to optimize the spectral transmittance of RGB filter for single-chip CCD camera.

Multi-Spectral Imaging Systems

Multi-spectral imaging systems which we have developed is consisted of three parts, image acquisition system which is constructed by (1) five-band CCD camera and three dimensional camera used laser projection, (2) image processing system to estimate reflection spectra, and (3) display system based on color adaptation model and spectral printing system. These systems are controlled by three package software named Image Digitizer, Image Estimator and Image Reproducer. Developed multi-band camera and spectral transmittance of five filter used in the camera are shown in Fig. 1. and Fig. 2.

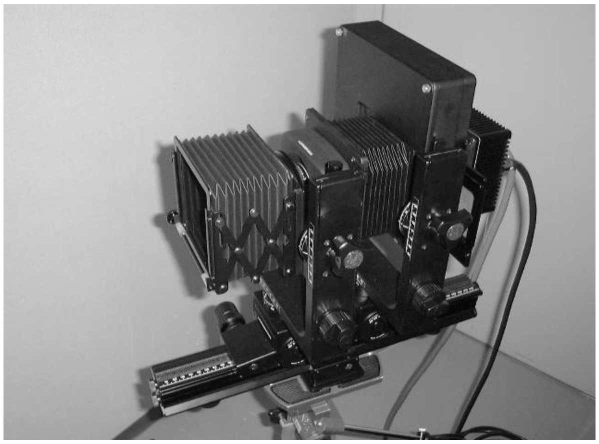


Figure 1. Developed multi-band camera

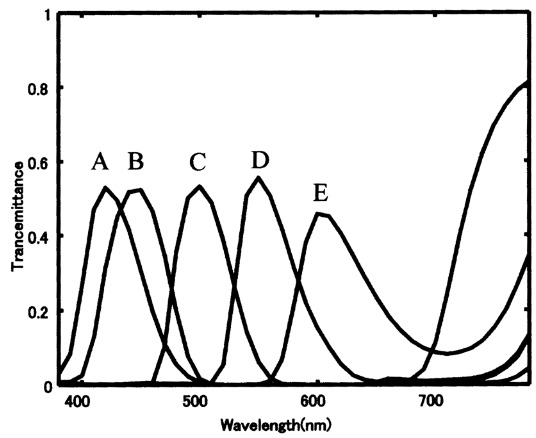
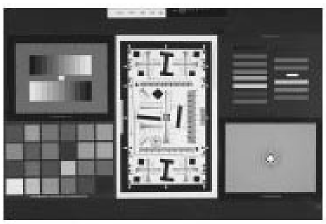


Figure 2. Spectral transmittance of five filters used multi-band camera



(1) Chart

(2) Oil paint

(3) Japanese Paint

(4) Object at rest

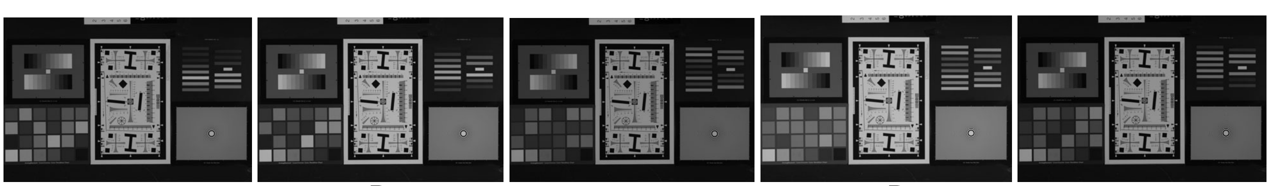
(5) Bottle

(6) Fruits

(7) Portrait

(8) Wool

Figure 3. Eight kinds of standard spectral images



A B C D E

Figure 4. Five-band images of Chart

Standard Spectral Image

We made eight kinds of object (1) **Chart**, (2) **Oil paint**, (3) **Japanese paint**, (4) **An object at rest**, (4) **Fruits**, (6) **Bottle**, (7) **Portrait**, (8) **Wool** as shown in Fig. 3.

These images are recorded as five band images with 16bits quantization level and three different sampling numbers (1) 2032×3056, (2) 1016×1528, (3) 508×764 as Tiff format. Figure 4 shows the five band image of Chart.

Chart includes Macbeth Color Checker, ISO resolution chart for digital camera, gray scale and zone plate. This **chart** image is used for evaluation of sharpness, resolution, tone reproduction and color reproduction of the multi-spectral imaging systems. **Oil Paint** and **Japanese Paint** are used to evaluate of painting reproduction for digital archives. **An object at rest** and **fruits** are used to evaluate of color reproduction, particularly colorfulness. **Bottle** is used for the evaluation of Gloss of the objects as metal and glass. **Portrait** is for the evaluation of skin color and **Wool** is used for the texture evaluation of the object.

CD-ROM recorded those images include the data of spectral radiant distribution of Standard Illuminant A, B, C and D65, spectral sensitivity of CCD, spectral transmittance of five filters using the five-band camera shown in Fig. 3 and spectral reflectance of Macbeth color checker. Program source of Wiener estimation method written by Matlab and C language to estimate of reflectance spectra of the object is also recorded on the same CD-ROM.

Computer Simulation of Color Reproduction

The camera response V_i^{xy} (i=R,G,B) of the object can be represented as follow

$$V_{i_i}^{xy} = \int f_i(\lambda)E(\lambda)L(\lambda)S(\lambda)o^{xy}(\lambda)d\lambda \quad i = R,G,B \quad (1)$$

where *(x, y)* is coordinate of the object and λ is wavelength of visible ray from 400nm to 700nm, $O^{xy}(\lambda)$ is reflectance spectra of the object, $S(\lambda)$ is spectral sensitivity of CCD, $L(\lambda)$ is spectral transmittance of taking lens and $f_i(\lambda)$ is spectral transmittance of filter. In this equation, as we know the reflection spectral of the object $O^{xy}(\lambda)$, then the color reproduction of the object in different spectral characteristics of illuminant, lens transmittance, spectral sensitivity of CCD and spectral transmittance of separation color filter can be estimated by computer simulation.

The image quality of CCD camera is dependent on many factors such as structure of CCD, interpolation method and spectral characteristics of imaging devices. We consider here the designing of spectral transmittance of RGB filters. In the optimization of spectral transmittance of RGB filter, we assumed that CCD with interline structure and Bayer type color filter array used bi-linear interpolation.

We also assumed that spectral transmittance of filters $f_R(\lambda)$, $f_G(\lambda)$, $f_B(\lambda)$ has Gaussian distribution as

$$f_i(\lambda) = \exp\left\{-\frac{(\lambda-\lambda_i)^2}{\sigma_i^2}\right\} \qquad i = R,G,B \qquad (2)$$

where λ_i is a central wavelength[nm], and σ_i is a half width [nm] of filter. The peak wavelength and half-width of filter was estimated and optimized by using simulated annealing method. In the optimization, the average color difference in S-CIELAB color space[5] between standard image and calculated from CCD camera with assumed spectral transmittance in Eq. 2 was used as a cost function. Figure 6 shows the schematic diagram of the optimization process. Optimum spectral transmittance of filter was determined to minimize the color difference calculated from various filter combinations. Figure 7 shows those obtained spectral transmittance of RGB filters in three different object (a) Object at rest, (b) Bottle, (c) Portrait. It became clear that the optimum spectral transmittance of filter is dependent on the object contents.

R	G	R	G
G	B	G	B
R	G	R	G
G	B	G	B

$$G: \begin{bmatrix} 0 & 0.5 & 0 \\ 0.5 & 1 & 0.5 \\ 0 & 0.5 & 0 \end{bmatrix} \qquad R,B: \begin{bmatrix} 0.25 & 0.5 & 0.25 \\ 0.5 & 1 & 0.5 \\ 0.25 & 0.5 & 0.25 \end{bmatrix}$$

Figure 5. Baye type color filter array and bi-linear interpolation

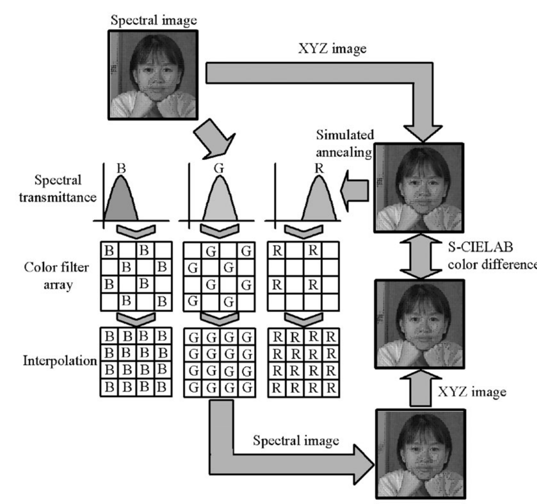
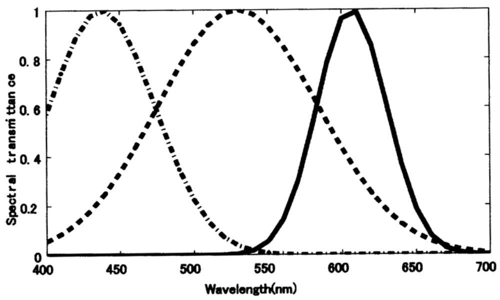
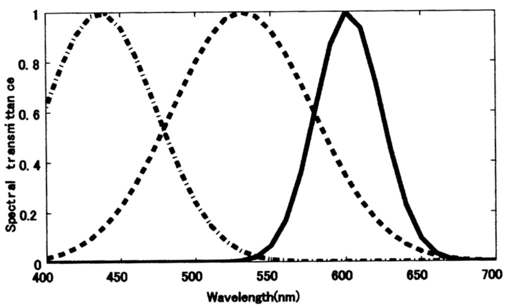


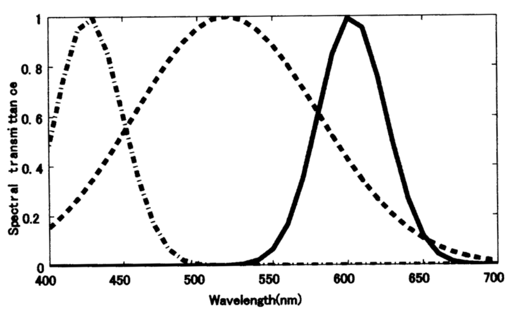
Figure 6. Schematic diagram of filter optimization process



(a) Object at rest



(b) Bottle



(c) Portrait

Figure 7. Optimized spectral transmittance of RGB filter in three different objects

Conclusion

In this paper, we introduce the standard spectral images taken by developed multi-spectral systems. Eight kind of object were recorded as five bands image with 16bits quantization levels on the CD-ROM as Tiff format. Sample program to estimate the reflection spectra from five bands image used Wiener estimation method is also presented on the same CD-ROM. Optimization of spectral transmittance of RGB filter for single chip CCD camera was also presented by using the standard spectral image. We hope that scientists and engineers use the standard spectral image proposed in this paper.

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Biographies

Tatsuhiko Fujimaki was born in Gunma, Japan, on 23rd April 1979. He received B.E. degree in department of information and image science from Chiba University in 2002. Now, he is the master course student in Chiba University. He is interested in multi spectral imaging.

Norimichi Tsumura was born in Wakayama, Japan, on 3rd April 1967. He received the B.E., M.E. and D.E. in applied physics from Osaka University in 1990, 1992 and 1995, respectively. He moved to the Department of Information and Image Sciences, Chiba University in April 1995, as assistant professor. He is currently associate professor since 2002, and also researcher at PREST, Japan Science and Technology Corporation (JST). He was visiting scientist in University of Rochester from March 1999 to January 2000. He got the Optics Prize for Young Scientists (The Optical Society of Japan) in 1995, and Applied Optics Prize for the excellent research and presentation (The Japan Society of Applied Optics) in 2000. He received the Charles E. Ives award in 2002 from the IS&T. He is interested in the color image processing, computer vision, computer graphics and biomedical optics.

Yoichi Miyake has been professor in the Department of Information and Image Sciences, Chiba University since 1989. He received the B.S. and M.E. in Image Science from Chiba University in 1964 and 1968, respectively. He received Ph.D. from the Tokyo Institute of Technology. During 1978 and 1979 he was an academic guest of Swiss Federal Institute of Technology. In 1997, he was a guest professor of University of Rochester. He received the Charles E. Ives award in 1991 from the IS&T. He became a fellow of IS&T in 1995. He also received Electronic Imaging Honoree of the Year in 2000 from SPIE and IS&T. He is one of the pioneers of multi-spectral imaging. He was served as president of Japanese Association of Science and Technology for Identification and the Society of Photographic Science and Technology of Japan. He is currently served as vice president of IS&T.