Development of Spectral Sensitivity Measurement System of Image Sensor Devices

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Abstract

Colors reproduced by image processing system are affected by various physical factors. The spectral sensitivity of the image sensor is one of the important factors. We developed a spectral sensitivity measurement system which is composed of simple optical system and color imaging system. The color signal generated from the optical system is acquired and analyzed by the color imaging system. The spectral sensitivities of R,G,B color sensors of a CCD camera are determined experimentally.

Introduction

Colors reproduced by image processing system are affected by various physical factors. They include the spectral power distribution of illuminant, spectral characteristics of image sensor like video camera, CCD camera, scanner, and image display device like various kinds of monitor, and printer. Especially the spectral sensitivity of image sensor is a very important factor. Even in the same illuminant the color also looks different according to the spectral sensitivity of the image sensor used. To find the real color of the object, the spectral sensitivity of the image sensor must be known precedently.[1-5]

In this study, the spectral sensitivity measurement system which is composed of the optical part and the color imaging part is developed and a color CCD camera is tested experimentally. Each monochromatic light generated from the optical part is captured by a color CCD camera and the digital output value is measured in the color imaging part. This process continues changing the wavelength throughout the visible spectrum. Also γ-value which represents the non-linear response characteristics of each *R,G,B* color sensor is determined by varying the intensity of monochromatic light.

With these values, the spectral sensitivity of a color CCD camera can be determined. This result shows the peak wavelengths and bandwidths of spectral sensitivity curves of *R,G,B* color sensors, which are critical parameters in the evaluation of color rendering.[6]

Theory

When we look at a certain object, we perceive its color like follows

$$S = \int E_\lambda R_\lambda V_\lambda d\lambda \tag{1}$$

where S is the stimulus, E_λ is spectral distribution of illuminant, R_λ is the spectral reflectance of the object, and V_λ is spectral sensitivity of human eye. Spectral sensitivity of human eye is represented by 3 color matching functions $V_{\lambda k}$ (for $k = 1, 2, 3$). Thus the stimulus is also represented by 3 values S_k.

When we use image sensors, $V_{\lambda k}$ is replaced by $D_{\lambda k}$, the spectral sensitivities of image sensors. And Eq.(1) is converted as follows

$$S_k = \int E_\lambda R_\lambda D_\lambda d\lambda \tag{2}$$

The color of the object depends on the the distribution of illuminant. But even in the same illuminant, the color also looks different according to the spectral sensitivity of the image sensor used. In other words, each image sensor produce different color. If we want to know the real color of the object under given illuminant, we must know $D_{\lambda k}$ precedently.

For example, white paper has spectral reflectance R_λ of 1 in the whole visible spectrum. In that case Eq.(2) is represented

$$S_k = \int E_\lambda D_{\lambda k} d\lambda \tag{3}$$

Another factor must be considered for reproduction of color. Generally, the output signal ρ_k from the image sensor, which is the only detectable signal, is not S_k itself. The relation between ρ_k and S_k is like follows[7],

$$\rho_k = S_k^{1/\gamma_k} = [\int E_\lambda D_{\lambda k} d\lambda]^{1/\gamma_k} \tag{4}$$

where γ_k is the characteristics of each color sensor and it represents the non-linear response of the output signal to the intensity level of illuminant. If γ_k is given

$$\int E_\lambda D_{\lambda k} d\lambda = \rho_k^{\gamma_k} \tag{5}$$

If we use monochromatic light of intensity 1 and of wavelength λ', E_λ is replaced by δ(λ-λ'). Then, Eq.(5) can be rewritten as

$$\int \delta(\lambda - \lambda') D_{\lambda k} d\lambda = D_{\lambda' k} - \rho_k^{\gamma_k} \tag{6}$$

Now, by repeating the above process at every wave-length in 20nm interval throughout the visible spectrum, $D_{\lambda k}$ the spectral sensitivity of any image sensor can be determined.

As a result, measurement of γ_k and $D_{\lambda k}$ is necessary for reproduction of real color of object.

Spectral Sensitivity Measurement System

This system is divided into optical part and color imaging part as shown in Figure 1. The optical part was constructed to generate monochromatic lights. The white light from the light source (tungsten-halogen lamp) is made monochromatic by the interference filter in 20nm interval over a range of from 400 to 700nm. The intensity of monochromatic light of each wavelength is controlled using the neutral density(ND) filter and detected by multichannel photodetector(MCPD). Each monochromatic light is projected on the white screen in order. Color imaging part is composed of image sensor to be tested, color image frame grabber(DT2871) embedded in computer, and color monitor. The colored monochromatic light reflected from the white screen is captured by image sensor. The output signal is sent to the color imaging system. The digital output values converted to the amounts of stimuli by computer and can be determined spectral sensitivity of the image sensor.

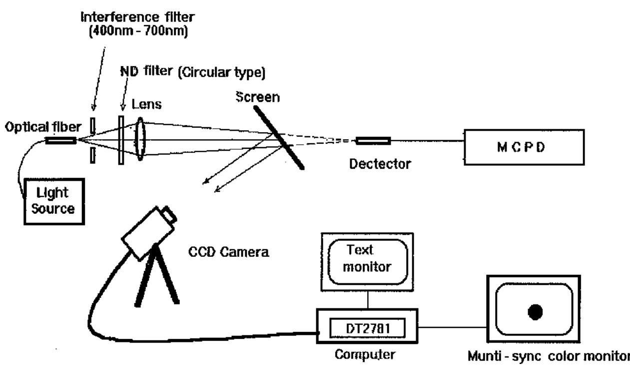


Figure 1. The schematic diagram of spectral sensitivity measurement system

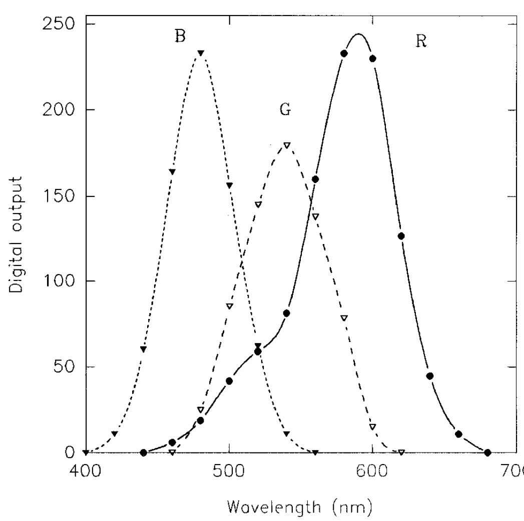


Figure 2. R,G,B digital output values for monochromatic lights whose relative intensity distribution is equal to that of 3,000K Plankian radiator

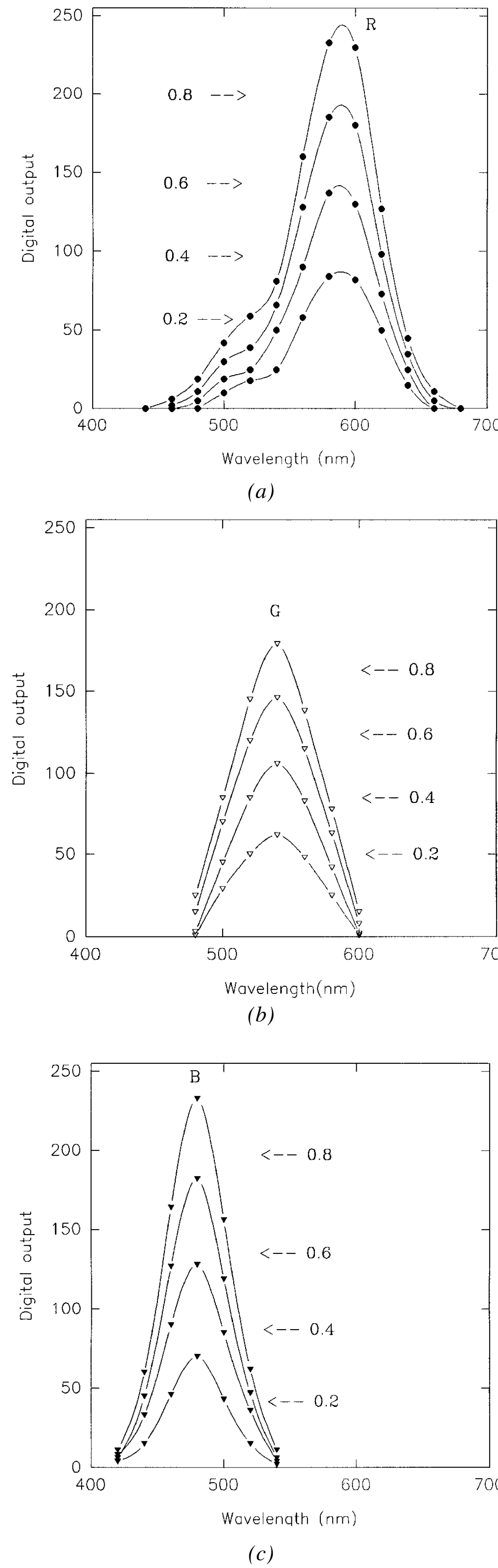


Figure 3. The variation of the digital output values according to the intensity level of illuminant, (a): R, (b): G, and (c): B

Measurement of Spectral Sensitivities of a Color CCD Camera

Camera to be tested is set to capture the monochromatic light reflected from the white paper (assumed to have reflectance 1). The output signal from the camera is measured digitally in the color imaging part. This process continues changing the wavelength in 20nm interval over a range of from 400 to 700nm. The relative intensity distribution of the monochromatic light is adjusted to that of 3,000K Plankian radiator, to which the camera used in this experiment was white-balanced. Figure 2 shows the R,G,B digital output signals produced from the camera. The above process is repeated varying the relative intensity level of illuminant at 0.8, 0.6, 0.4, and 0.2. The results are shown in Figure 3(a),(b), and (c).

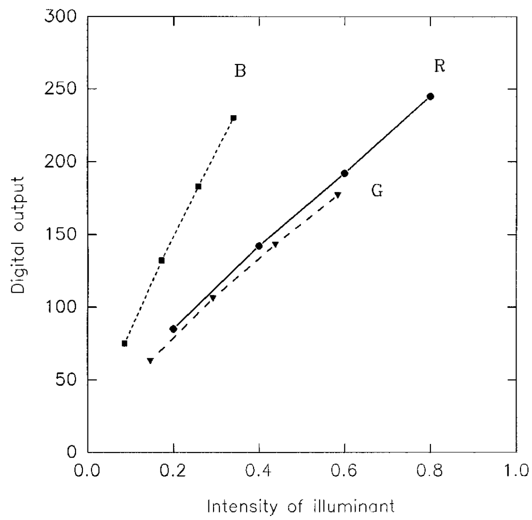


Figure 4. Digital output values at the peak wavelength against the intensity level of illuminant

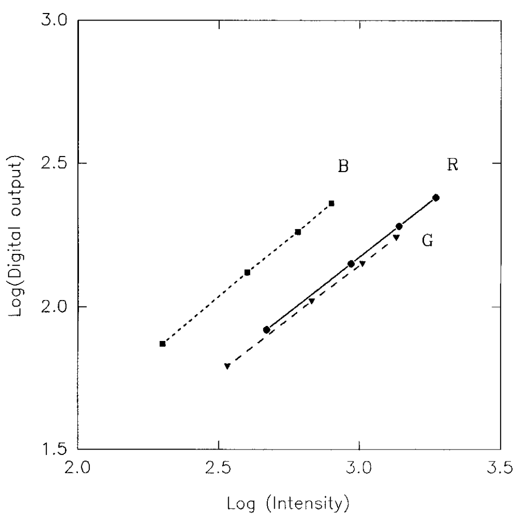
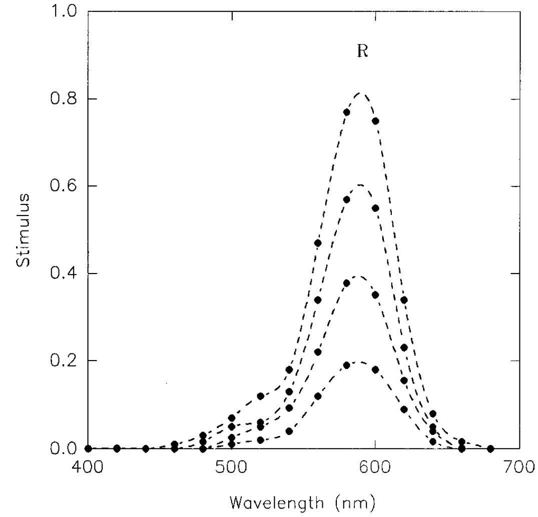
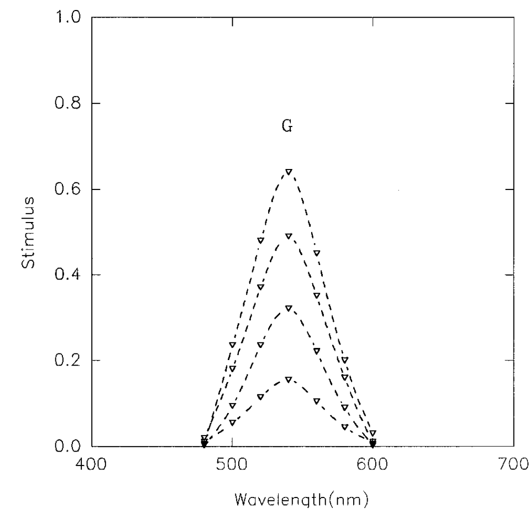


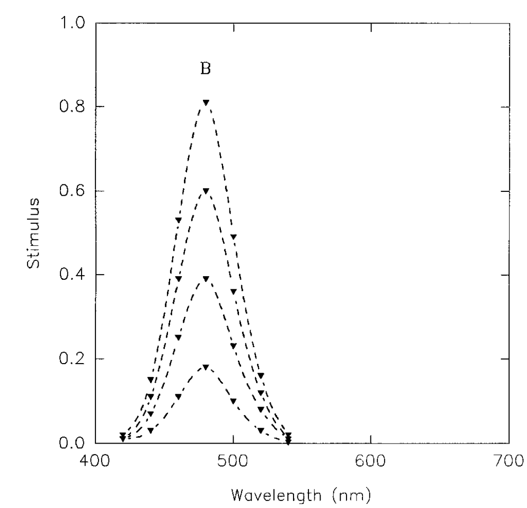
Figure 5. Figure 4 is replotted in the log-log scale



(a)



(b)



(c)

Figure 6. The stimulus curves as a function of wavelength. (a): R, (b): G, and (c): B

In Figure 4, the digital output values at the peak wavelengths of R,G,B color sensors are plotted against the intensity level of illuminant. This Figure is replotted in the log-log scale, as in Figure 5. The points are on the straight line. γ-values determined from the slopes of the straight lines are 1.38, 1.35, and 1.23 for each R,G,B color sensors. Using the γ-values, the amounts of stimuli were calculated from the digital output values, and the results are presented in Figure 6(a),(b), and(c). Figure 6 shows how the sensors respond as the illuminant intensity level varies. To avoid the effect of illuminant intensity, the curves were recalculated for light intensity level of 1, and are shown in Figure 7. This is the spectral sensitivity of a color CCD camera. The curves in Figure 6(a), (b), and (c) are consistent to the R,G,B curves in Figure 7, respectively. This shows that this camera is now operating well in accordance with the relation expressed in Eq.(4).

In Figure 7, the wavelength of the maximum sensitivity of each curve is about 480, 540, and 590nm respectively, while on the other, sensitivities below 440nm and above 640nm are very low. And between 480nm and 520nm, the three sensitivity curves of R,G,B are crossed, so the maximum sensitivity of G sensor is not high as the other sensors.

These analyses coincide well to the fact that this camera didn't reproduce blue color and red color well, and green color appeared a little reddish.

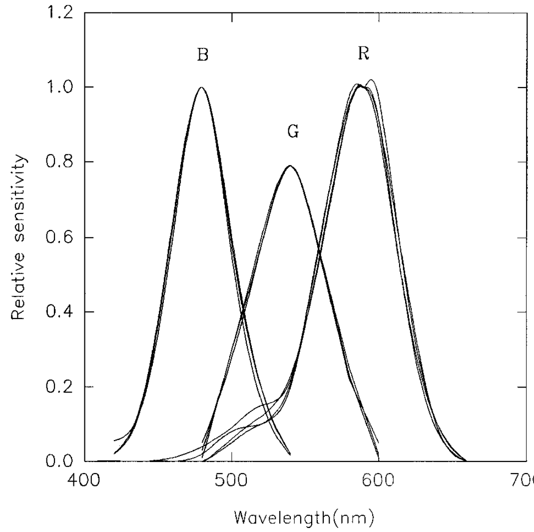


Figure 7. The spectral sensitivity of a color CCD camera

Conclusion

The spectral sensitivity measurement system is developed. This system is composed of the optical part and the color imaging part. The color signal captured by the image sensor is analyzed in the color imaging part. For testing, the spectral sensitivity of a color CCD camera is measured experimentally.

From the measured spectral sensitivity, the peak wavelengths and the crossed wavelength region of spectral sensitivity curves of R,G,B color sensors are shown clearly.

It is found that this system is very convenient to measure the spectral sensitivity and useful for the evaluation of color rendering of image sensor.

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References

1. Brian A. Wandell, "The Synthesis and Analysis of Color Images*", IEEE Transactions on Pattern Analysis and Machine Intelligence, PAMI*-**9**(1), pp.2-13 (1987).
2. Brian A. Wandell, "Color Rendering of Color Camera Data", *Color Research and Application* **11** pp.s30-s33 (1986).
3. Laurence T. Maloney and Brian A. Wandell, "Color Constancy; a method for recovering surface spectral reflectance", *J. Opt. Soc. Am.* **3**(1), pp.29-33 (1986).
4. S. O. Park, H. S. Kim, J. M. Park and J. K. Eem, "A Study on the Calibration for Color Imaging System", 大眞 論叢 第 2輯 pp.53-63 (1994),, Dae Jin University.
5. S. O. Park and S. G. Yu, "Development of Color Measurement Techniques by Using Color Image Processing System", Korea Institute of Standards and Science, *KRISS*-**91**-61-IR, *KRISS*-**92**-061-IR, *KRISS*-**93**-061-IR.
6. Richard S. Hunter and Richard W. Harold, *The Measurement of Appearance*, pp.51-54, 1987, John Wiley & Sons. Inc.
7. W. N. Sproson, *Color Science in Television and Display Systems*, pp. 27-47, 1983, Adam hilrer Ltd.