Improving the Color Match between Monitor and Hardcopy

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Abstract

*Recently, soft proof, which can confirm the color reproduction of printed matter on a monitor, is coming into wide use in the field of graphic arts. However, there is a problem that the color appearing on the monitor is different from that of printed matter, even though the L*a*b* value of the monitor's white point has been adjusted to that of the paper's white measured by a spectroradiometer. According to our experiment, L*a*b* value of the monitor was more greenish blue in the case of LCD and bluish in the case of CRT than that of the paper, even though the color of the monitor was matched to that of the paper by visual calibration. In this paper, we assume that the cause of this phenomenon is bright line spectrums of the monitor and illuminations measured by a spectroradiometer were blurred by optical systems in the spectroradiometer. To solve the problem, we propose a method to correct this error by enhancing the bright line spectrums and report the effect of our method with two kinds of monitors (LCD and CRT) under three kinds of illuminations. After enhancing spectrums, L*a*b* values of the monitors were almost the same as that of the paper.*

1. Introduction

Since color management systems are becoming common and high-performance LCDs can be bought for a reasonable price, soft proof that can confirm the color reproduction of printed matter on the monitor is coming into wide use in the field of graphic arts. To confirm the color of images by soft proof, it is necessary to match the color reproduction of the monitor with that of the printed matter accurately.

By the way, ISO 3664 [1] recommends the viewing condition for soft proof. ISO 3664 P2 condition recommends "The illumination at the plane of viewing shall approximate that of CIE standard illuminant D50." and "The illuminance at the center of the viewing surface shall be 500 lx ± 125 lx." On the other hand, we usually adjust chromaticity of white point of a monitor to D50 and luminance to 80cd/m^2. However, luminance of the paper under the viewing illumination is not the same as that of the monitor and chromaticity of the paper is not the same as that of D50. The reasons of this problem are nonflatness of spectral reflectance of the paper and difficulty to control illumination accurately.

To solve this problem, we proposed a method [2]. This method measures and adjusts the color of the monitor white point and paper white under viewing illumination directly, so it can adjust the chromaticity and luminance of the monitor's white point to those of the paper's white accurately. However, it has reported that appearance of the monitor has been different from that of paper even though tristimulus values of both have been same. The cause of this phenomenon has not found out.

Then, we proposed another method. The method adjusts the color of a monitor to that of paper by visual calibration [3]-[5]. In addition, the expert committee in specification of color monitor for printing industries has also recommended matching the monitor white point with the color of paper by visual calibration[6]. However, visual calibration is often unstable.

In these backgrounds, to make accurate soft proof possible, color appearance of the monitor should be the same as that of the printed matter, when colorimetric values of both are adjusted by spectroradiometer. In this paper, we would like to find and solve the cause of the phenomenon mentioned above. First, we matched the color of the monitor's white point with that of the paper's by visual calibration and measured both colors using a spectroradiometer. Next, we assumed that the cause of this phenomenon was bright line spectrums of the monitor and illumination measured by a spectroradiometer were blurred. Then, we propose a method to correct this error and report the effect of our method for LCD and CRT under three kinds of illuminations.

2. Visual Color Matching Experiment

In this experiment, we matched the color of the monitor's white point with that of the target paper's by visual matching, measured both colors with a spectroradiometer, and evaluated the color difference between the monitor and the target paper.

2.1 Procedure

The devices and subjects of this experiment were as follows.

Monitors: (1) NANAO ColorEdge CG210 (LCD)
(2) BARCO Reference Calibrator (CRT)
Illumination: (1) D50 fluorescent lamp for color evaluation
(CRT was tested only under D50 illumination)
(2) General fluorescent lamp (4200K)
(3) Tungsten lamp
Target paper: OK Topcoat plus
(Typical coated paper in Japan)
Spectroradiometer:PHOTO RESEARCH, Inc, PR-705
(spectral interval :2nm, aperture size: 0.5degree)
Subjects: 8 people (7 male and 1 female)
all having normal color vision

Figure 1 shows the device configuration of this experiment. A color patch was displayed on the monitor. Target paper was placed next to the color patch. Brightness and hue of the color patch changes when subjects push a button on the monitor.

Subjects observed the color patch and the target paper from a distance of 50cm. Then, they matched the brightness and hue of the color patch with that of target paper five times for each illumination and monitor combination. Next, the matched color patches and target paper were measured by a spectroradiometer. The spectroradiometer was placed at the same position as the subjects.

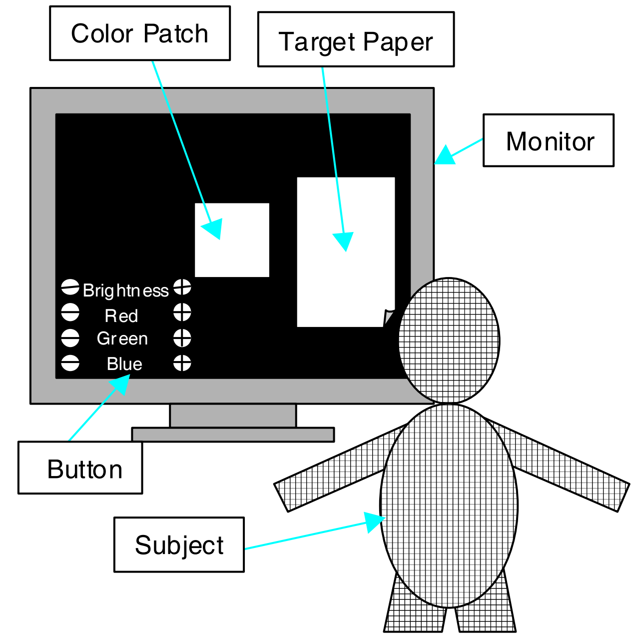

Figure 1. Device configuration of visual color matching experiment.

2.2 Results

Figure 2 shows the results of this experiment. The measured values of the matched color patches and the target paper were plotted on the CIE 1931 a*b* plane. L*a*b* was calculated from XYZ which was calculated from the spectrum. XYZ was normalized with Y = 100.

In the case of a LCD, the matched monitor white of all subjects and illumination conditions were plotted on the left below of the target paper. These results indicate that measured values of monitor were more greenish blue than those of the target paper even though both colors look the same. In the case of CRT, the matched monitor white of all subjects were plotted under the target paper. These results indicate that measured values of the monitor were more bluish than those of the target paper.

Table 1 shows the matching accuracy of these experiments. All ΔE in this paper were Euclidean distances between the monitor and the paper in CIE 1931 L*a*b* color space. This table shows that the CRT was matched more accurately than LCD to the target paper.

Table 1. Matching accuracy between monitor and paper

Type of Monitor	Illumination	ΔE
LCD	D50 fluorescent lamp	2.80
LCD	General fluorescent lamp	9.06
LCD	Tungsten lamp	6.42
CRT	D50 fluorescent lamp	2.06

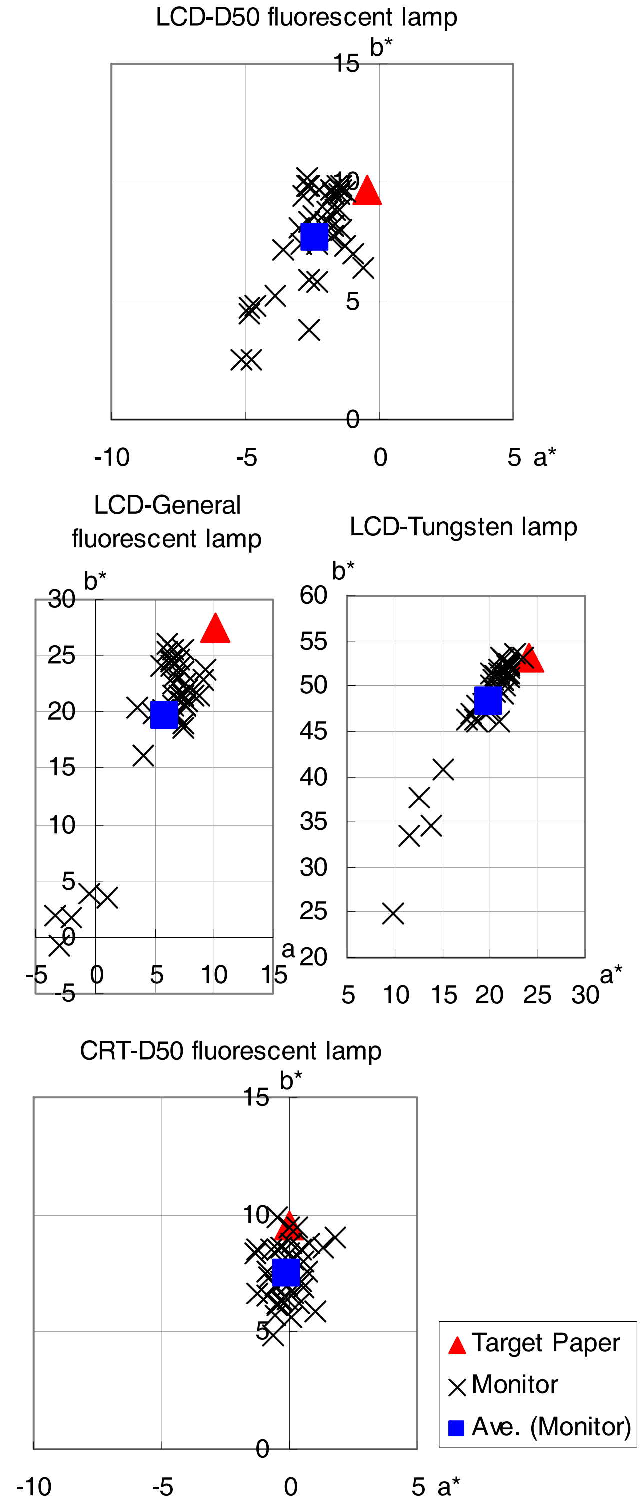

*Figure 2. a*b* of the matched monitor and target paper. (note: difference in scale)*

3. Simulation to Improve Matching Accuracy

A general spectroradiometer gets spectral radiant intensity by diffracting incoming light using a grating. Spectral radiance value blurs because of defects of the optical system: resolution of grating, size of aperture and so on [7]. In particular, the blur affects the bright line spectrum strongly.

Aperture size is one of the most effective factors that blur bright line spectrums. A small aperture gives a sharp spectrum, and a large one blurs the spectrum. One reason of this phenomenon is the input angle for grating affects the reflect angle. Equation 1 is the grating equation. This equation can explain the mechanism of dispersion by grating. The spectrum of wavelength λ, which enter to the grating with α degree, reflect to β degree.

$$d(\sin\alpha \pm \sin\beta) = m\lambda \qquad \text{(equation 1)}$$

- λ: wavelength
- α: input angle
- β: reflect angle
- d: grating interval
- m: diffraction order ($m = 0, \pm1, \pm2...$)

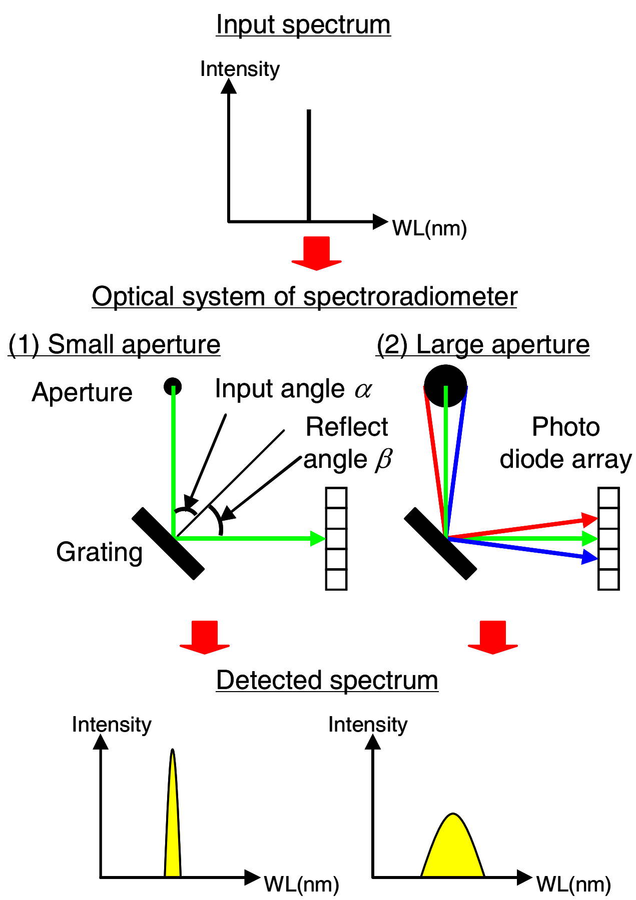

Figure 3. A general flow chart how spectrum is blurred by spectroradiometer.

Figure 3 is a general flow chart how spectrum is blurred by spectroradiometer. In the case of small aperture, a sharp spectrum is seen (see (1) in Figure 3). On the other hands, a broad spectrum is seen in the case of a large aperture (see (2) in Figure 3). We will describe why a large aperture gives a broad spectrum. The detail of (2) in Figure 3 is as follows. First, a very sharp spectrum goes through an aperture. A large aperture makes the range of input angle α broad. Next, broad α make the range of β broad. Therefore, the photo diode array detects a blurred spectrum.

In this paper, we assumed a mismatch between visual estimation and measured value is caused by a blur of the bright line spectrum. In this section, we tested to correct bright line spectrum.

3.1 Principles of the correction

The spectral radiant intensities of a monitor and paper were measured by a PR-705 spectroradiometer (spectral interval :2nm, aperture size: 0.5degree, half bandwidth: 5nm). The spectral radiant intensity of a tungsten lamp, which has no bright line spectrum, can measure accurately in this condition. On the other hand, it is difficult to measure the spectral radiant intensity of a fluorescent lamp which has a bright line spectrum accurately because of blurring of the bright line spectrum. So, we enhanced the spectrum by using equation 2. The level of enhancement can be controlled by changing the enhancement coefficient α in equation 2.

$$P'(\lambda) = P(\lambda) + \alpha\{P(\lambda) - P(\lambda - n)\} + \alpha\{P(\lambda) - P(\lambda + n)\} \qquad \text{(Equation 2)}$$

- $P(\lambda)$: Original spectral radiant intensity at λ nm
- $P'(\lambda)$: Enhanced spectral radiant intensity at λ nm
- n: Wavelength spacing
- α: Enhancement coefficient

3.2 Results

We have evaluated the colorimetric values calculated from an enhanced spectral radiant intensity $P'(\lambda)$. L*a*b* was calculated from $P'(\lambda)$ by the same method as that of section 2. ΔE between the monitor and the target paper for each α are plotted in Figure 4. We used the averaged L*a*b* values of all subjects and all trials. Table 2 shows α which can get minimum ΔE for each conditions and the ΔE before and after enhancement. Figure 4 and Table 2 indicate that enhancing the spectral radiant intensity were able to reduce ΔE between the monitor and the target paper although the optimal value of α were different for the monitor and illumination. In Figure 5, corrected values of the matched monitor and the target paper using equation 2 were plotted on a*b* plane. α was selected to minimize the average ΔE. In all illumination conditions and monitors, the matched monitor and target paper were plotted in nearer places compared with Figure 2.

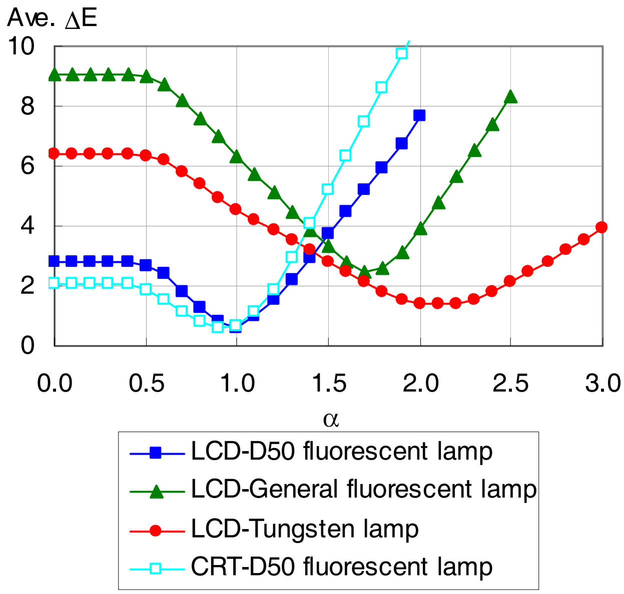

Figure 4. ΔE between monitor and target paper for each α..

Table.2 Optimum α and ΔE between monitor and target paper

Type of Monitor	Illumination	α for minimum ΔE	ΔE (before enhancement)	ΔE (after enhancement)
LCD	D50 fluorescent lamp	1.0	2.80	0.60
LCD	General fluorescent lamp	1.7	9.06	2.50
LCD	Tungsten lamp	2.1	6.42	1.37
CRT	D50 fluorescent lamp	0.9	2.06	0.57

Direction and length of hue shift because of enhancement changed due to number, wavelength, and intensity of a bright line spectrum. In particular, the effect of enhancement by equation 2 affected the bright line spectrum strongly. For example, the a*b* value of the target paper under a tungsten lamp, which has no bright line spectrum, changed very little. On the other hand, the a*b* value of the target paper under a fluorescent lamp and a LCD, which has some strong bright line spectrum, changed very much. In the case of the CRT, which has less bright line spectrum than LCD, a*b* value changed less than the LCD. Spectral radiant intensities before and after enhancement are seen in Figure 6. In the case of target paper under tungsten lamp, the shape of spectral radiant intensity hardly changed. On the other hand, in the case of LCD, CRT and the paper under fluorescent lamp, the shape of spectral radiant intensity were enhanced and the peak value of the bright line spectrum became bigger before enhancement.

Comparing a LCD to a CRT, the amount of the effective bright line spectrum for the CRT is less than the LCD (The bright line spectrum near 710nm of the CRT is not effective because of less sensitivity of the human visual system). This is the reason why ΔE between a matched CRT and target paper was relatively small before enhancing.

These results indicate it is necessary to correct the bright line spectrum for adjusting the color appearance of a monitor to that of paper accurately by using a spectroradiometer. Furthermore, enhancement by equation 2 is effective to correct blurred spectral radiant intensities.

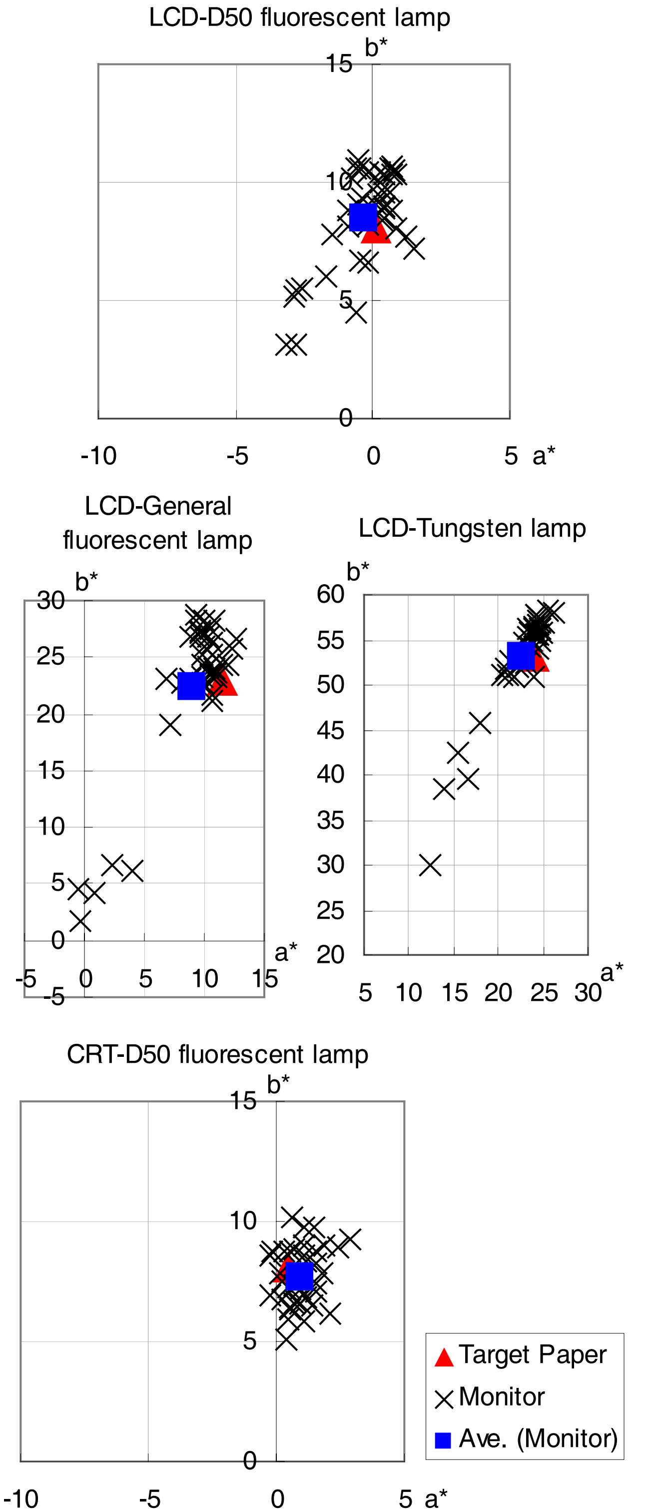

*Figure 5. a*b* of a matched monitor and target paper after enhancement. (note: difference in scale)*

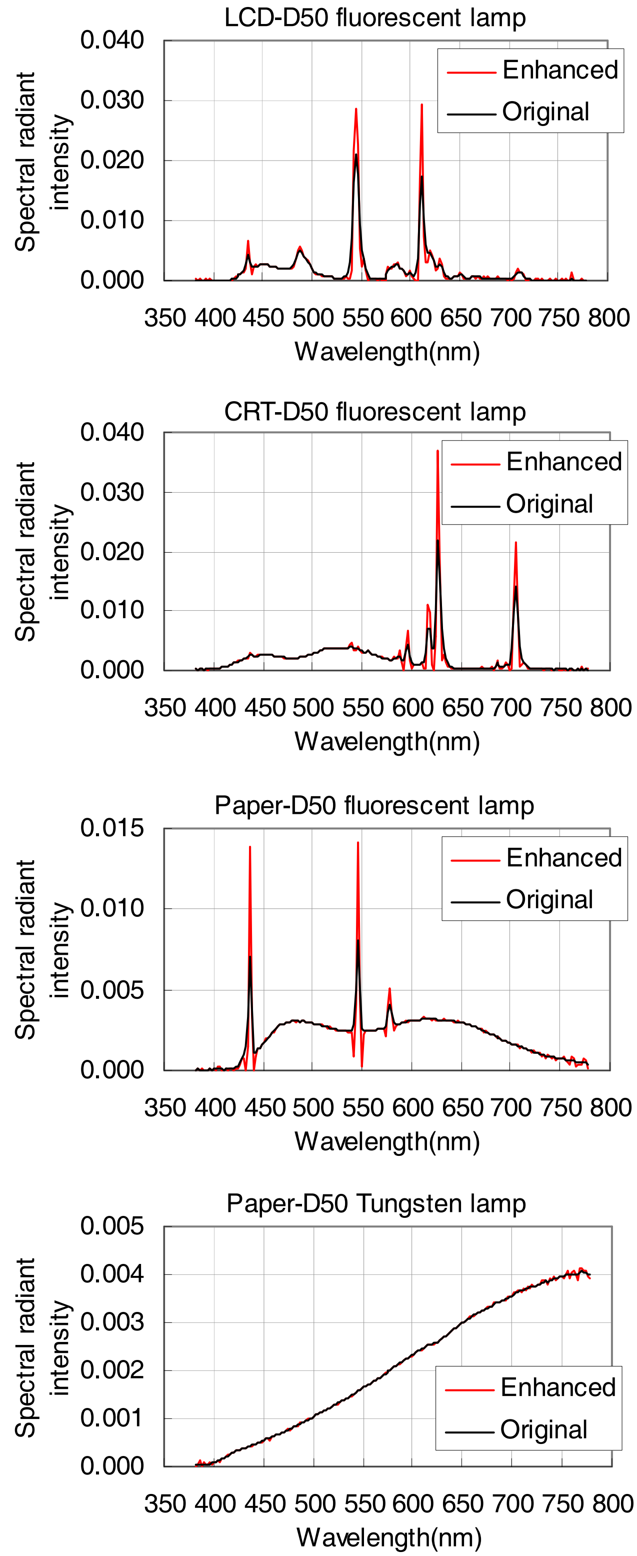

Figure 6. Spectral radiant intensities before and after enhancement.

3.3 Discussion

In Figure 5, a point of matched monitor averaged of all subjects was plotted near that of target paper. However, some points of each subject were plotted far from that of target paper. Though this paper does not describe this in detail, there is a tendency for a specific subject to match the color of the monitor to a color far from target paper. It is inferred from this result that spectral sensitivity of each subject is different.

By the way, the optimal value of α in all conditions could be the same because equation 2 corrects the blurs of the optical system of a spectroradiometer and blurs from all of the conditions are the same. There are many reasons to explain this phenomenon; variations of visual matching, the environment of measurement, variations of illumination, imperfect correction by equation 2, and so on.

4. Conclusions

We have calculated the L*a*b* value of a visually matched monitor and target paper using enhanced spectral radiant intensity measured by a spectroradiometer. These method were able to match the evaluation of color difference between the monitor and paper by a spectroradiometer to the evaluation by visual appearance. This result suggests that the optical blur of spectroradiometer causes decreasing matching accuracy. In conclusion, the monitor calibrated by our method can be used for accurately soft proof.

We will study the cause of the mismatch by specific subject in the future. To improve the accuracy of our method, we will apply our method to other brands of spectroradiometers, monitors and illuminations, and search for a better method to enhance the spectral radiant intensity. A further direction of this study will be to prove the cause of these phenomena not only practically but also theoretically.

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Author Biography

Tohru Sugiyama received his B.E. and M.E. degrees from Tokyo Institute of Technology (Japan) in 1992, 1994 respectively. He has since worked as a engineer at Dai Nippon Printing Co., Ltd. He has developed the monitor calibration system. Now, he is researching and developing color management systems for graphic arts. He is a member of the Japanese Society of Printing Science and Technology, He is also a member of the Vision Society of Japan.