

Problems in Color Proofing from the Colorimetric Point of View

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Review

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1. Introduction

In recent years, as digitalized workflow has gained popularity and ever-higher work efficiency is being required in printing, design and other graphic-related industries, the importance of colorimeters used for color proofing is increasing. However, when using a colorimeter for actual color proofing, there are some problems: perceived color difference in visual inspection does not always match the color difference measured by the colorimeter, and each colorimeter has its own instrumental error. In this paper, I will explain the problems related to colorimeters and introduce a new technology developed by us to overcome such problems. First, I will discuss the range of the "problems in color proofing" to be addressed in this paper. Color proofing in a broad sense also includes soft proofing (or monitor proofing) where color proofing is performed on a monitor. In this paper, however, I will focus on the problems of matching colors on a proof output by DDCP (Direct Digital Color Proofing) to those on the final printed material.

2. Factors in the differences between visual color evaluation and measured color values

If the color values measured for two printed materials are identical, those colors should be perceived as basically the same when inspected visually. But a mismatch between the perceived colors of these printed materials may occur. The cause of the mismatch can be differences between the observation conditions of visual inspection and the measurement conditions of the colorimeter. On the other hand, when two identical copies of printed materials are displayed side-by-side, they look the same even under

different observation conditions. In other words, the perceived colors of two printed materials with different properties may not match each other visually even if the color values measured by a colorimeter are identical. The possible factors causing such problem are shown in Table 1 below:

Table 1: Factors in the differences between visual color evaluation and measured color values

1 Effect of geometry	Differences in the paper surface condition, etc. may result in the colors of two materials matching when using a certain measurement geometry (geometric conditions of illumination and light reception) which includes the effects of surface reflection and light diffusion, but not matching if the geometry changes.
2 Effect of metamerism	Because the colorants used in proofing are different from those used in printing, colors on a proof may match those on a printed material under a certain light source, but not match under other light sources.
3 Effect of fluorescence	When printing is performed on two pieces of paper with different contents of fluorescent whitening agent, colors on those two papers may match under a certain light source, but not match under other light sources.

Profile

Shinji Yamamoto

1988 - Joined Minolta Camera Co., Ltd
2008 onwards - Engaged in the development of a spectrophotometer for printing



2.1 Effect of geometry

As shown in Fig. 1, the reflection of light from the printed material is composed of specular reflection and diffuse reflection. Specular reflection is higher when the light is reflected from a high-gloss paper, and is lower when the light is reflected from a low-gloss paper. Generally, people look at the colors of a printed material from a direction with no specular reflection. ISO standards specify that the color measurement of printed materials shall be conducted with an instrument geometry of 45° illumination / 0° light reception (or 0° illumination / 45° light reception)¹⁾.

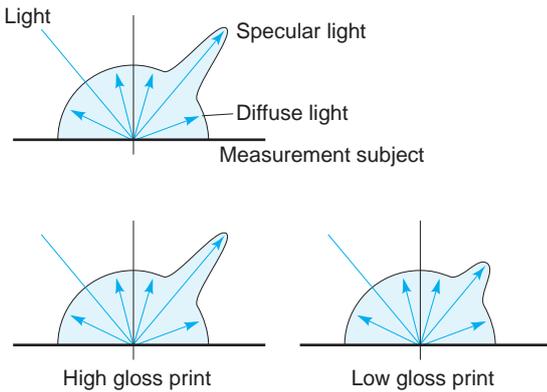


Figure 1: Differences in reflection for differences in gloss

However, when we look at a printed material in a white-walled room or a room illuminated by multiple light sources, the material to be observed is illuminated from various directions and the observation conditions become similar to when the material is illuminated by diffuse lighting as shown at right in Fig. 2. Because of this, the colors we look at include specular reflection. The weaker the specular reflection (i.e., the lower the gloss of paper) is, the smaller the color difference is between 45° illumination / 0° light reception geometry and diffuse illumination / 0° light reception geometry (or the reverse of each geometry).

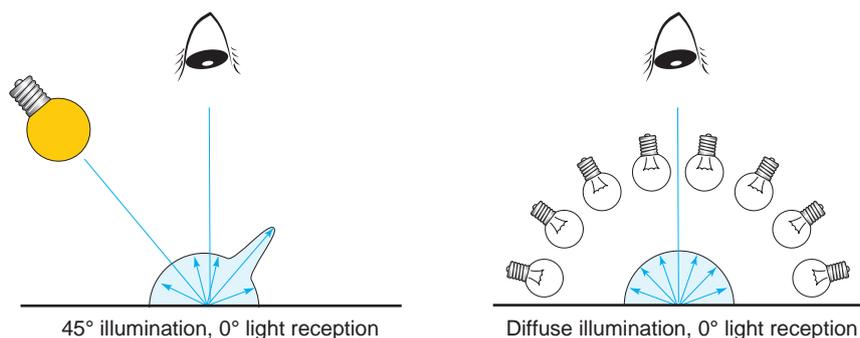


Figure 2: Differences in geometry

When we compare colors of materials printed on papers with different levels of gloss, it is necessary to pay attention to the observation conditions such as the light source position and the viewing angle. However, the environment in which printed materials are viewed often has conditions similar to diffuse illumination due to the need to secure an appropriate illuminance level and ease of viewing the materials. Thus, geometric differences occur between visual inspection and measurement by a colorimeter.

2.2. Effect of metamerism

After checking and adjusting colors based on the proof to match the desired colors under a certain light source, the resulting colors on the printed material may look different from the desired colors under other light sources because the colorants used in proofing are different from those used in the final printing. For example, Sample A and Sample A' in Fig. 3 have different spectral radiance factor curves, but when they are observed under CIE Illuminant D65 (hereinafter referred to as D65), their colorimetric values are identical. However, under CIE Illuminant A, the color difference $\Delta E^*_{ab} = 8.71$, and Sample A and Sample A' appear different from each other. In this way, the spectral distribution of the illuminant greatly affects the color values. For visual inspection of the printed material, the use of CIE Illuminant D50 is specified in ISO 3664: 2009.

2.3 Effect of fluorescence

When we compare two pieces of paper side by side, one containing high levels of fluorescent whitening agent and the other containing low levels of fluorescent whitening agent, the colors of these papers may look the same under the daylight near windows that includes a relatively high level of ultraviolet radiation, but under fluorescent lights that include only a low level of ultraviolet radiation, the paper containing high levels of fluorescent whitening agent may look yellowish compared to the paper containing low levels of fluorescent whitening agent. This is because the fluorescent whitening agent reacts with ultraviolet radiation and emphasizes the blue color to make paper appear whiter. In the case of printed material, a part of the incident light is transmitted through the inks and reflected diffusely by the layer containing fluorescent whitening agent. Therefore, the fluorescence action also affects the visual appearance of colors printed on the paper material. Moreover, the effects become even larger in areas with a lower percentage of halftone dots because the ink-dot-covered areas and areas with no ink coexist.

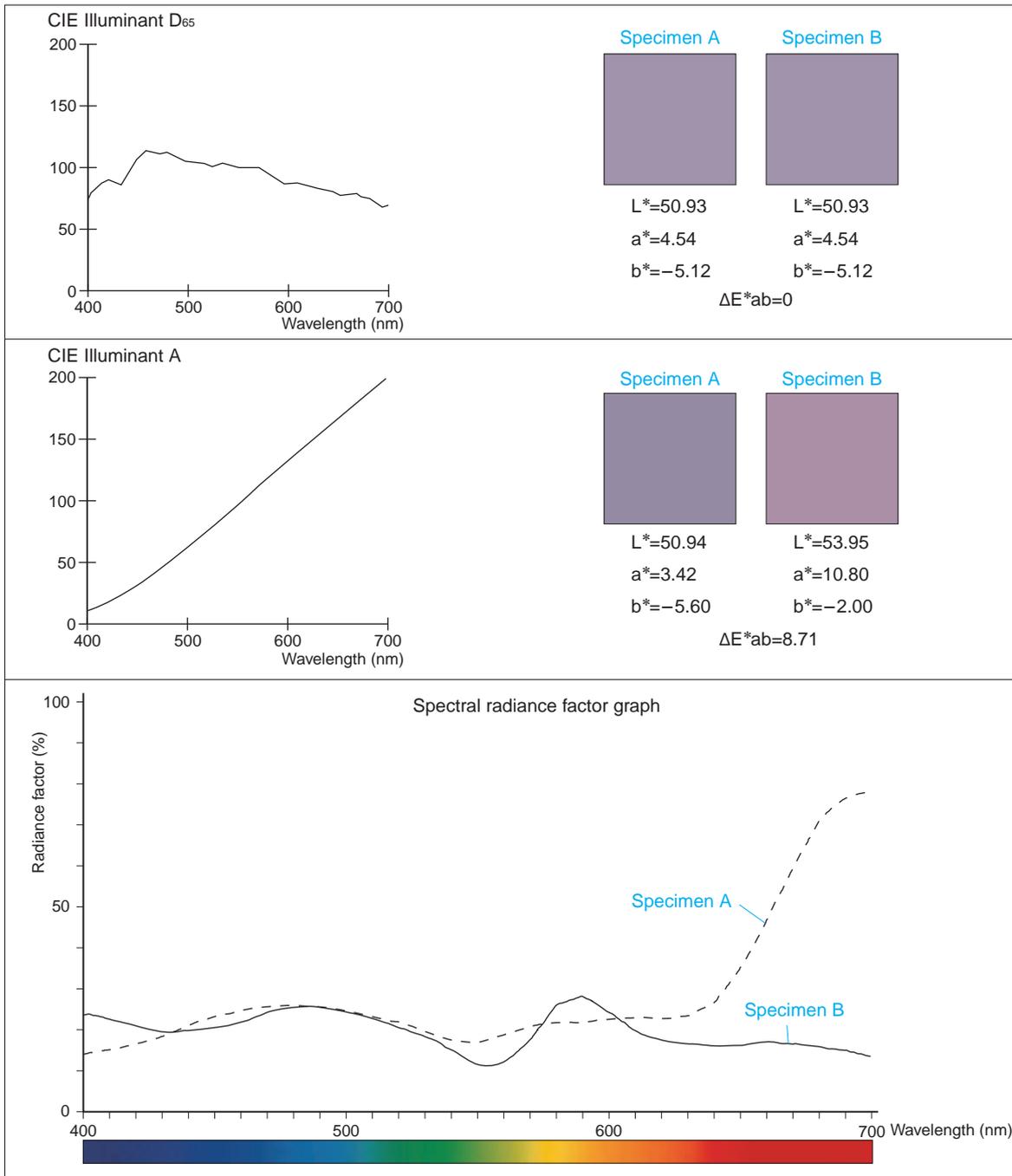


Figure 3: Effect of metamerism

Although the phenomenon that colors printed on paper with different levels of fluorescent whitening agents look different depending on the illuminant seems to be similar to the phenomenon of metamerism, it is necessary to distinguish them. In terms of measuring instruments, a spectroradiometer is useful for evaluating the effects of metamerism. It allows evaluation of the effect by calculating the colorimetric values under different illuminants from measured spectral radiance factor values. But the effect of fluorescence cannot be evaluated by conventional colorimeters under the same conditions as visual inspection. This is because the conventional colorimeter uses a built-in light source for measurement while the amount of excited fluorescence varies depending on the spectral distribution of

the light source actually used for visual inspection. In order to solve these problems, ISO 13655: 2009 "Graphic technology -- Spectral measurement and colorimetric computation for graphic arts images" has been published and color evaluation including fluorescence under CIE Illuminant D50 has been standardized. Color evaluation under CIE Illuminant D50 is thus internationally required²⁾. The fluorescent Spectrodensitometer FD-5 and FD-7 developed by Konica Minolta Sensing can virtually change the illumination light source by calculation, enabling accurate colorimetry taking paper fluorescence into consideration. The following is an explanation of the features of FD-5/FD-7.

3. Colorimetry including paper fluorescence

The effect of paper fluorescence is determined by the amount of fluorescent whitening agent contained in the paper and the characteristics of the illuminant.

When a piece of paper containing fluorescent whitening agent is exposed to light, the fluorescent whitening agent absorbs light energy in the ultraviolet and violet wavelength regions, and emits the absorbed energy as light at a different wavelength within the visible light range. The visible light range is about 380 to 780nm, and the fluorescent whitening agent absorbs light at wavelengths of around 360nm and radiates light at wavelengths of around 460nm as shown in Fig. 4.

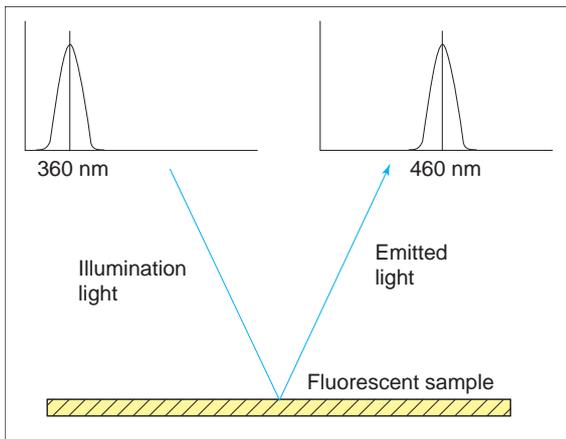


Figure 4: Diagrammatic model of fluorescence

The spectral distribution of several illuminants is shown in Fig. 5. The figure shows that the amount of fluorescence excitation energy around 360nm varies greatly among the illuminants. Therefore, the amount of excited fluorescence will also vary depending on the illuminant as follows: D65 > D50 > A > A (UV-cut) in decreasing order of fluorescence excitation energy.

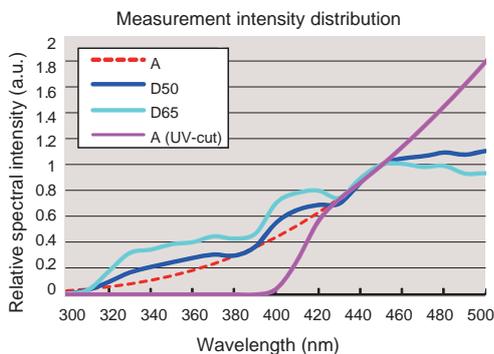


Figure 5: Spectral distribution of various illuminants

The spectral radiance factor curves obtained from paper whiteness measurements are shown in Fig. 6. It shows that the effect of fluorescence on the spectral radiance factor is extremely large. The color differences measured on the printed color control patch are shown in Fig. 7. The lower

the percentage of halftone dot area is, the larger the effect of paper whiteness is, and thus color differences become larger. Moreover, the data of cyan shows that there is a color difference (ΔE^*ab) of less than 2 even when the percentage of dot area is 100%. This indicates that cyan was largely affected by the light that penetrated the ink layer. For general colorimeters used at printing sites, a tungsten lamp that corresponds to CIE Illuminant A is used as a light source. On the other hand, a light source corresponding to CIE Illuminant D50 is used for visual inspection. Therefore, when colors are evaluated by visual inspection after color proofing using a colorimeter, color differences occur. These differences are almost the same degree as the differences between CIE Illuminants D50 and A shown in Fig. 7. If ΔE^*ab is 3 or more, problems in color matching occur. Moreover, if a colorimeter equipped with a UV cut filter is used, the color difference becomes even larger.

Our newly developed FD-5 and FD-7 can prevent the occurrence of the differences mentioned above by calculating the measured values and outputting the resulting values as if those values were measured under a light source equivalent to CIE Illuminant D50 based on our proprietary VFS (Virtual Fluorescence Standard) technology using a built-in ultraviolet LED³⁻⁵.

Moreover, our FD-5/FD-7 has a function to measure the relative spectral distribution of the illumination light in a lighting environment, so it can measure color values under the actual lighting environment by using the measured relative spectral distribution as its illuminant.

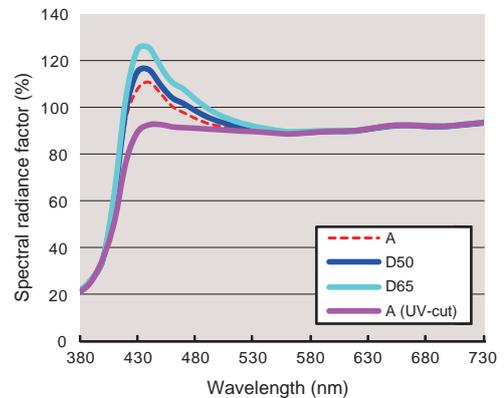


Figure 6: Differences of spectral radiance factor from paper for various illuminants

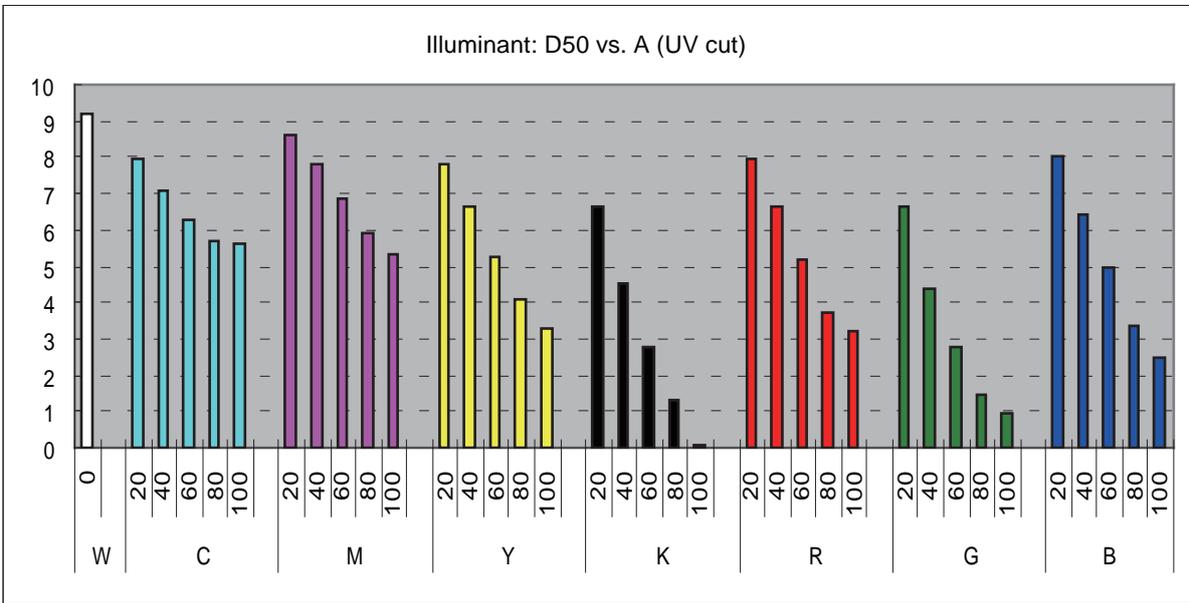
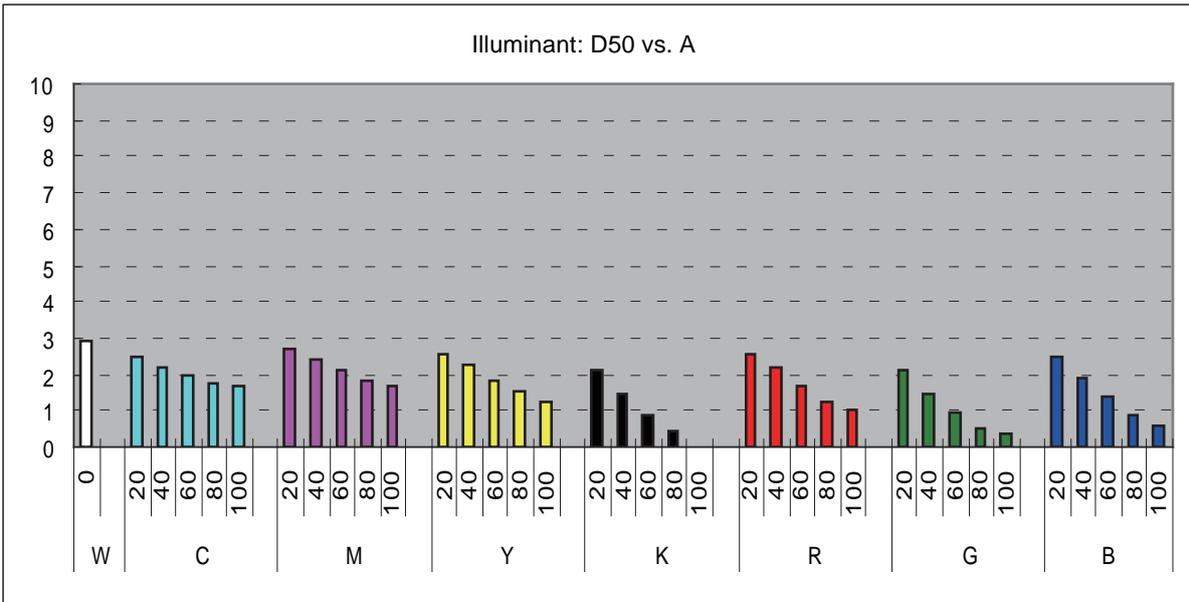


Figure 7: Color differences in printed material for various illuminants (ΔE^*_{ab})

4. Other problems with colorimeters

In addition to the difference between visual color evaluation and measured color values, there are some other problems with colorimeters, which must be noted.

4.1 Differences between instruments

The characteristics of measuring instruments including colorimeters vary between makers, models and even individual instruments. In the case of colorimeters, even if we measure the same sample using colorimeters of different makers, there may be a difference of about $\Delta E^*_{ab}=3$ on some colors. Therefore, due attention must be paid to the use of colorimeters for color proofing and color management of printing. Colorimeters from the same maker should be used and it is desirable not to change the colorimeter in the workflow of color proofing.

4.2 Reliability

When we use measuring instruments for a long time, in general some characteristics change gradually. In the case of colorimeters, the characteristic change in the direction of brightness and the characteristic change in the direction of wavelength are the two major factors that cause errors (Fig. 8). The characteristic change in the direction of brightness does not become a serious problem because the change can be corrected by the white calibration performed by the user. But the change in the direction of wavelength cannot be corrected by white calibration on conventional instruments, and becomes the main cause of error when a colorimeter is used for a long time. Konica Minolta's FD-5 and FD-7 (Fig. 9) automatically perform wavelength calibration using a UV LED each time white calibration is performed, so the effect of that characteristic change can be restrained even when the instrument is used for a long time.

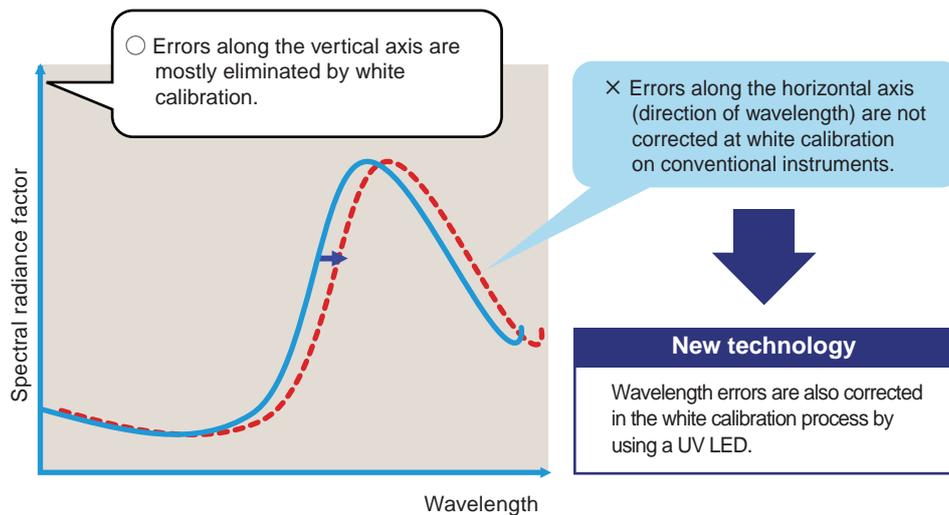


Figure 8: Characteristic changes (errors) when a colorimeter is used for a long time



Figure 9: Konica Minolta Sensing's FD-5/FD-7

5. Conclusion

Konica Minolta's proprietary VFS technology allows users to easily take color measurements taking into consideration the fluorescence of the paper substrate that is an issue in color match proofing. Although current ICC profiles are defined by color values, profiles based on bi-spectral characteristics that include both spectral and fluorescence characteristics have been studied as one approach. In the overall proofing workflow, with the progress of colorimeters and profiling methods that take fluorescence into consideration, we can also expect great progress in color proofing.

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