

Measuring the Transmittance of Transparency Print using a Reflectance Measurement Instrument

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Abstract

This paper describes a method to derive spectral transmittance data from spectral reflectance measurement data. The model was verified with colors of the IT8.7/3 color charts. The spectral reflectance of printed colors was measured with an automated reflectance measurement system by placing the transparency sheet on the measurement table with paper backing. The spectral transmittance of these color patches was also measured manually for comparison. The combined transparency and backing reflectance data were used to derive the transmittance data based on a special model. The CIELAB color differences between the model-derived transmittance data and the actual measured transmittance data were computed. The average, maximum and standard deviation of CIELAB color differences between the model-derived data and the actual transmittance data for the 928 colors were found to be 1.6, 8.7 and 1.21, respectively. There were generally larger deviations for darker colors due to lower signal noise ratios.

Introduction

Current proven successful printer calibration algorithms usually require the measurement of large numbers of color samples. Automated spectral reflectance measurement systems have been commercially available and have served as a necessary tool for printer characterization and calibration. To measure multiple color samples on a sheet, there are two ways to accomplish multiple measurements with a single measuring head: moving the sample sheet through the measuring head, or moving the measuring head across the sample sheet. Moving the sample sheet through the measuring head can be less desirable because of the potential technical inconvenience involved in paper feeding. However, such measurement systems can be easily modified for both reflectance measurement and transmittance measurement. Moving the measurement head across the sample sheet does not have the potential problems related to paper feeding, but it has the technical difficulty of combining reflectance measurement and transmittance measurement within one system. In this case, it essentially requires moving the measuring detector module together with the special illumination source, which needs to be placed directly under the transparency sheet while the measuring detector module is above the transparency sheet. It is for this reason that systems designed under this principle normally do not have the automated transmittance measurement capability, at least not to the author's knowledge.

The rapid development in printing technology has been constantly raising the standard on office printer printing quality. Color quality of printed transparency is becoming increasingly important with the increased use of color in the business environment. Color calibration labs equipped with automated systems that are only capable of reflectance measurement may feel the need for separate automated measurement systems. If a separate instrument is used, it may raise the problem of intra-instrument agreement because different instrument manufacture may use different spectral measurement technologies. For example, one manufacturer may use optical gratings that are easily capable of a spectral bandwidth of 5nm while the other manufacturer may use optical filters that are only capable of wide spectral bandwidths. There may also be discrepancies between the master color standards used by these manufacturers. This paper explores the possibility of deriving transmittance measurement data from reflectance data.

Methods

In both reflection and transmission, incident light energy can be transmitted, scattered, or absorbed by the inks/toners layers and the substrate. If the optical properties of inks or toners layer and property of the substrate are known, the combined optical property, the reflectance or transmittance, of the colorant layer and the substrate can be derived. On the other hand, if the optical properties of the substrate and that of the combined are known, the optical properties of inks or toners can be derived. Consequently, the transmittance of the same layers of inks or toners on transparency can be derived. To derive the proper model, the measurement geometry that will be used for the measurements have to be considered. In this paper, the

GretagMacbeth™ Spectroscan™ system was used. The system used the standard 0/45 measurement geometry.

The Model

If we assume that printing inks and toners have negligible amounts of optical scattering, Beer's law can be used to model the process. When a sheet of transparency print is placed on a reflective backing, the reflectance of the combined effect of the print and the backing can be measured. The process can be separated into two separate passes. In the first pass, parallel light from the instrument illumination system passes through the transparency print at a 45° angle and illuminates the reflective backing after losing a small portion due to multiple surface reflections. In the second pass, light of a certain angle to the normal of the backing diffusely reflected by the backing will pass through the transparency print and reach the optical detector of the instrument. The second pass is identical to the usual transmission measurement. If the measurement geometry is 0/0, the model can be easily written as,

$$t = \sqrt{\frac{r}{r_g}} \quad , \tag{1}$$

where t is the spectral transmittance; r is the reflectance of transparency print and the backing combined; r_g is the reflectance of the backing. For the 45/0 measurement geometry, the first pass (45° pass) through the transparency print is $\sqrt{2}$ times longer (oblique angle effect) than the second pass (0° pass). If we assume the optical absorption coefficient of the transparency base as k_0, and ignore the angle effect for the toner or ink layer, we need to consider a factor of $e^{(1-\sqrt{2})k_0}$. The absorption coefficient k_0 can be derived based on the measurement of the transmittance t_0 of the transparency base with the following equation,[1]

$$K_0 = \ln\left(\frac{2K_1 t_0}{-(1-K_1)^4 + \sqrt{(1-K_1)^4 + 4K_1^2 t_0^2}}\right) , \tag{2}$$

where k_1 can be set to be 0.04. The argument to ignore the angle effect for the toner and ink layer on the 45° pass was that the halftone natural of the prints compromised the angle effect.

For the 100% black, the two pass reflectance should be virtually zero, however, the measured reflectance may not be zero because of toner and ink scattering and other surface irregular reflections.[2] The measured reflectance therefore has to be compensated for such errors. Because of the potential halftone pattern variations, irregular surface reflection that will be picked up by the instrument will also vary. An empirical function may have to be used. In our case, the following correction function was preferred,

$$r_0 = r_b + \alpha(1 - \beta K_0) \quad , \tag{3}$$

where r_b is the reflectance of the 100% black patch; α=0.0185; β=5.735. Equation 1 can then be rewritten as,

$$t = \sqrt{\frac{r - r_0}{r_g e^{(1-\sqrt{2})k_0}}} \quad . \tag{4}$$

Measurement

The measurement procedure was set to measure all the parameters needed by Equation 4.

Results

Follow the model described by Equation 4, the 928 color patches in the IT8.7/3 target chart were printed using a electrophotographic printer and measured with the Spectroscan™ system with a special non-fluorescent high reflectance paper as the backing. The transmittance of the transparency base and the 100% black patch was measured as required by the model. The color patches were also measured individually with the manual transmittance measurement option of the Spectroscan™ measurement system used. The computed k_0 is shown in Fig. 1.

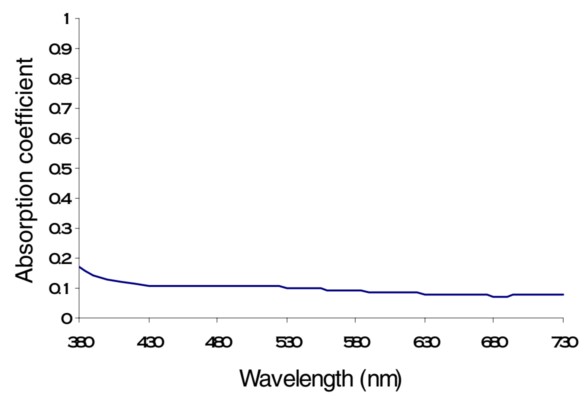

Figure 1. The spectral absorption coefficients of the transparency base used.

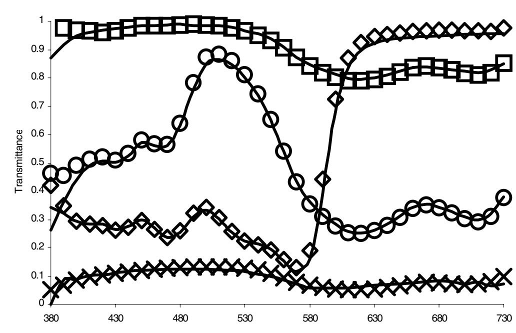

Figure 2. Typical measured and derived spectral transmittance (four color patches). The lines represent the measured transmittance, and the symbols represent the model-derived transmittance.

Typical model-derived transmittance in comparison with the measured transmittance are shown in Fig. 2. The solid lines are transmittance actually measured and the symbols that (close to the lines) are the corresponding model derived transmittance based on measured reflectance. The CIELAB color differences (DE) between the measured and model-derived transmittance were computed and the DE distribution of all the 928 color patches is shown in Fig. 3. The average, maximum and standard deviation of CIELAB color differences between the model-derived data and the actual transmittance data for the 928 colors was 1.6, 8.7 and 1.21, respectively.

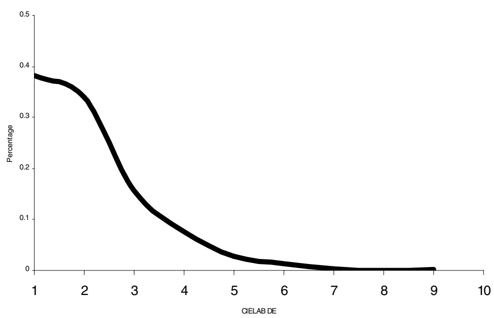

Figure 3. Frequency distribution of the 928 color differences (DE) computed based on the difference between the measured and model-derived transmittance.

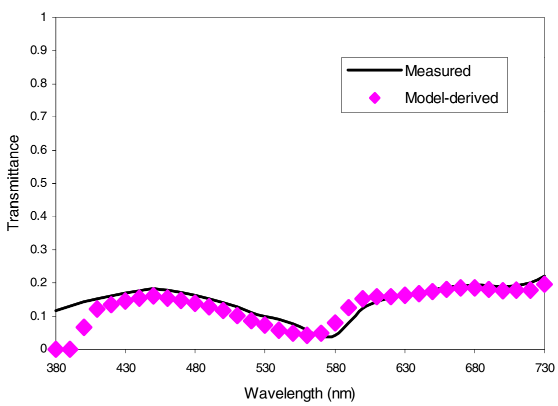

Figure 4. Comparison of the measured (solid line) and model-derived (symbols) spectral transmittance with the largest color difference (DE = 8.7).

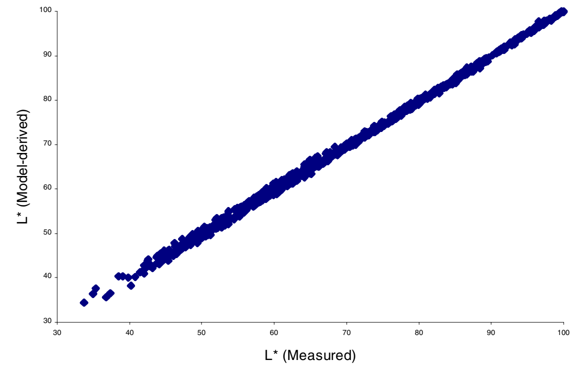

Figure 5. Measured L versus model-derived L*.*

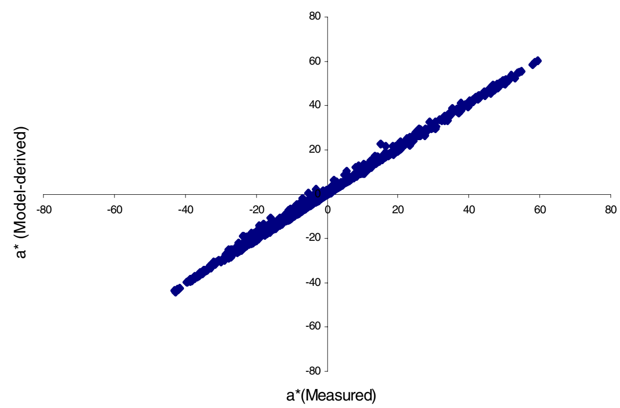

Figure 6. Measured a versus model-derived a*.*

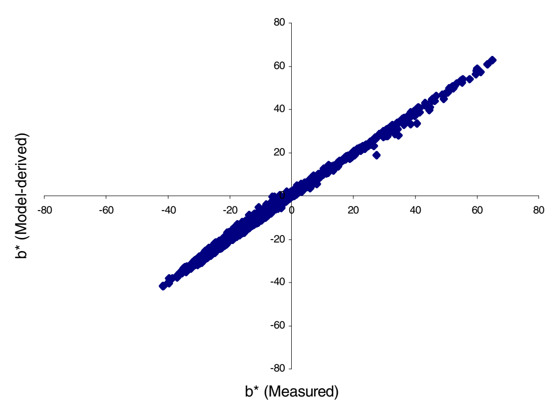

Figure 7. Measured b versus model-derived b*.*

Fig. 4 shows the worst-case spectral comparison with the largest CIELAB. The CIELAB L*, a*, and b* components computed based on the measured transmittance and the model-derived transmittance are plotted versus each other for all the 928 color patches and shown in Figs. 4-6.

Discussion

Figure 1 shows significant amount of absorption of the type of transparency base used and why it appeared to have a yellowish tint. The spectral transmittance comparisons shown in Fig. 2 prove that the model used was effective. As shown in Fig. 3, the color differences resulted from the differences in spectrum were mostly below 3 CIELAB DE. However, there were a significantly large number of colors that had color differences larger than 3 CIELAB DE. Fig. 5 shows that darker colors tend to have larger errors. Fig. 4 shows the case of the largest color difference. Fig. 6 and 7 show that the differences were relatively smaller in highly saturated colors. In this case, the color was dark and unsaturated. Although the model-derived spectral transmittance had the same basic shape as the measured, the color difference resulted from the spectral-shift type of error was large.

The errors seen here could have been the effects of a number of factors that were not accounted for in the model. The model did not consider the scattering power of the laser toners used. It was proved that laser toners could have a significant amount of scattering power.[3,4] For the light color patches, the small amount of scattered light to the instrument might be insignificant. However, when the color patches were dark, the contribution of light scattering could be significant. The model can be further improved if the toners scattering power is considered.

When the measured reflectance was low, the limited instrument signal noise ratio could result in a significant amount of error in derived transmittance. If we assume r_g=1 and differentiate Equation 1, we have,

$$dt = \frac{1}{2\sqrt{r}} dr \,, \qquad (5)$$

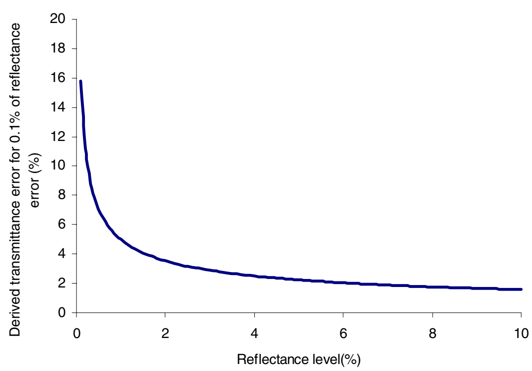

Figure 8. Dependence of model-derived transmittance error on the reflectance from an assumed reflectance measurement error of 1%.

Fig. 8 shows the plot of Equation (5), assuming the reflectance measurement error was the typical 1% and the low reflectance range of 0.1% to 10%. Fig. 8 clearly shows the potential large errors for the derived transmittance for low reflectance values. For dark color patches, the contribution of such errors could be large.

Conclusion

Spectral transmittance data of transparency print can be derived from the reflectance data by measuring the reflectance of the print on a white backing. The model presented here shows an average CIELAB DE error of 1.6 with a standard deviation of 1.21 for the 928 color patches of the IT8.7/3 chart when printed with an EP printer. Large errors can occur when the color patches are dark.

The scattering power of the toners used and the limited sensitivity of the measurement system can both contribute to errors in the derived spectral transmittance.

References

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Biography

Chengwu Cui received his BS degree in optics from Shandong University, MS in color science from Chinese Academy of Science and PhD in vision science from the University of Waterloo. From 1995 to 1999, he worked for GretagMacbeth as a color scientist. He is currently with Lexmark International. His research interests include human vision, ocular optics, image quality, color measure-ment, daylight simulation, computer color formulation and psychophysics.