Measurement Problems for Overhead Projection Transparency Printing Color Calibration

Chengwu Cui and Steven Weed
Lexmark International Inc., Lexington, Kentucky

Abstract

The color quality of overhead projection transparency is affected by the transparency print, the projector, the projection screen, and the viewing environment. For color calibration, there are commercial measurement instruments capable of transparency sample spectral and color transmittance measurement. However, projection stray light, sample scattering as in samples printed with EP technologies, and projector design parallax limitation as in reflective-type projectors makes using measured transmittance data to represent the projected colors inadequate. In this paper, we report our effort and findings on overhead projection transparency color measurement and calibration. We devised an automated measurement system based on a spectroradiometer to measure multiple projected colors automatically; the results are compared with that obtained by direct sample transmittance measurement with both diffuse illumination and collimated illumination. We concluded that projected colors should be measured for superior overhead projection transparency color calibration to compensate for regular stray light, sample scattering, and projector optical design limitations.

Introduction

In comparison to digital projectors, projection transparency offers the advantage of convenience. However, dramatic variations of viewing environments and projection systems and their design imperfections have created great challenges to transparency printing color calibration. Consequently, the expectation for the color quality of projection transparency is relatively low. With the rapid improvement in printing quality and speed of color EP and inkjet printers, the opportunities for improved color quality of projection transparency increases along with other printing quality attributes.

A critical step in color calibration is color measurement. The transparency projection color quality is affected by the transparency, the projector, the projection screen, and the viewing environment. Measurement and calibration of transparency projection color need to take into account of all these factors in order to make appropriate color calibration for the "average" end user.

Reflective print color calibration often starts with measuring many color samples to profile the color printing characteristics of a printer. The measurement geometry is usually set at 45/0 to simulate the actual situation that a reflective sample is viewed. There are also commercial measurement instruments for spectral and color transmittance measurement. As in a reflectance measurement system, the illumination configuration determines the type of transmittance data that a transmittance measurement system measures. For overhead projection transparency, the illumination and measurement geometry should be consistent with that of the projection system. If the illumination and measurement geometry do not simulate that of a projection system, the effectiveness of color calibration will be compromised. With adequate sample transmittance data and a "standard" projection and viewing system model, in theory, the final projected color may be able to be predicted to some extent.

If system modeling based on direct measured sample transmittance is insufficient to predict the projected colors due to the complexity of the interaction of various factors of a projection system, the ultimate measurement is then to directly measure the projected colors with a spot spectroradiometer or a spot colorimeter. Because many proven color calibration methods require the measurement of a large number of colors, it can be tedious if the measurement is performed manually one at a time.

In this paper, we report our experience with overhead projection transparency color measurement and calibration to show the potential large effect of stray light, sample scattering and projector design limitations. Although more controlled measurement using lab grade projection and measurement system will enable more adequate model developments, here we investigate the problems with currently off the shelf systems in a "reality-setting" to gain some insight into practical problems. We compare the results from two transmittance measurement instruments with that measured directly off the projection screen. We devised an automated measurement system based on a Photo Research PR650™ spectroradiometer to measure multiple projected colors automatically.

Theoretical Considerations

There are two typical types of overhead transparency projector. In one type, as shown in Fig. 1, a Tungsten-Halogen lamp illuminates the transparency sheet from below. A large Fresnel lens is mounted directly under the transparency sheet. The illumination assembly including lamp, reflector, and mirrors are packaged within a box and therefore this type of projector always comes with a boxy lighting stage. This type of projector is often referred to as the transmissive-type.

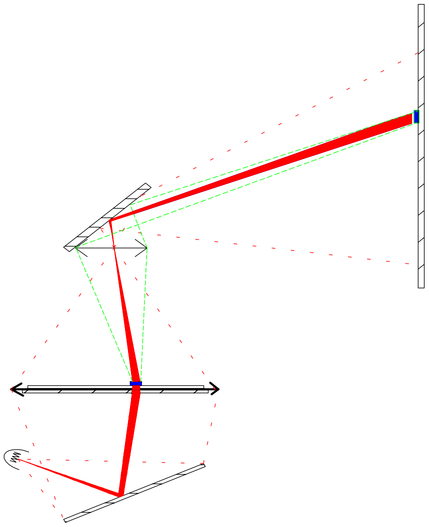


Figure 1. Optics and illumination of a transmissive-type projector.

In the other type, the Tungsten-Halogen lamp is mounted above the sample plane (often mounted together with the projection lens group) as shown in Fig. 2. A large Fresnel lens is also placed under the transparency sheet. A flat mirror is placed directly under the Fresnel lens. In contrast to the first type, this type of projector does not need the boxy illumination stage under the transparency sheet and therefore can be made compact. This configuration is often referred to as the reflective-type.

It is important to understand the role of the Fresnel lens. The purpose of the Fresnel lens in both types of projector is to converge light into the projection optics to achieve high illumination efficiency. The Fresnel lens is designed and placed to form a real image of the lamp (including the reflector) to the first principal point of the projection optics.

If the lamp is a perfect point source and the transparency is clear, no projection optics is needed because the transparency will be "projected" sharply on a receiving screen at any distance as shown by the shadowed areas in Fig. 1 and 2, respectively. Because the lamp cannot be considered a point source, light reaching a specific spot on the sample may originate from different spots of the lamp (including the reflector of the lamp). Light leaving a specific transparency location will have a solid angle that is not zero as in the hypothetical point source case, but small in comparison to a Lambertian surface. The role of the projection lens is to form a real image of the transparency sample on the projection screen by converging the light within the small solid angle onto a specific image location. Therefore, the illumination of transparency projection is neither diffuse nor collimated, depending on the specific dimensions of the projector.

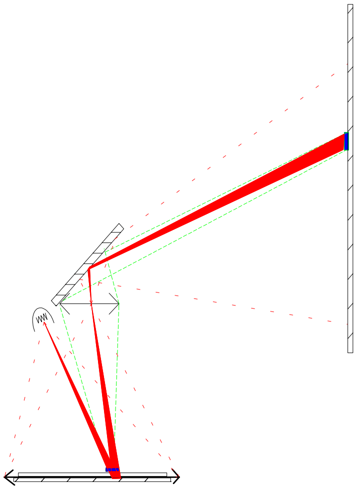


Figure 2. Optics and illumination of a reflective-type projector.

Illumination Uniformity

Because of the unique illumination system, the uniformity of projection is largely dependent on the illumination uniformity on the transparency sheet, which is related to lamp filament configuration and the design and workmanship of the lamp reflector. Regular projector lamps are normally rather crude in this respect and can produce large variations when illuminating the transparency sheet. The projection lens is normally designed to have an aperture large enough to avoid vignetting.

The illumination non-uniformity will appear as brightness variation when projecting an image on the screen. Such variance in brightness on an image can be remarkably discounted by the visual system.

Transparency Sample Scattering

For clear transparency samples such as film and high quality inkjet transparency prints, there is no or little scattering, light reaching the sample will be projected on the screen after spectral filtration. When the sample projected has scattering, a significant port of light will be scattered light and is likely to be lost in the form of stray light. EP transparency printing prints toners on the surface of the transparency stock. Toners normally have some scattering effect due to physical dimensions of pigments used.[1] Most importantly, because resin is the main component in toners, a printed dot will form a lenslet-like optical structure that diverges light in much the same way as forward scattering.[2] Because of this effect, color transparency sample printed by

EP printers generally appear to be washed out in color when projected. In the case of black and white printing, it is less a problem because the light lost due to scattering is roughly equivalent to being absorbed by the toner.

Direct Sample Transmittance Measurement

If sample light scattering is negligible, projected color can be predicted based on the transmittance data of the transparency sample measured directly with spectral transmittance instruments. However, if there is scattering from the sample, adequate collimated illumination simulating that of a projector has to be used to measure the so-called regular transmittance (in this case, transmittance that describes the proportion of light reaching the intended image location on the projection screen, as opposed to diffuse transmittance). If diffuse illumination or collimated illumination is used, measurement bias will be introduced depending on the degree of scattering from the sample. Instruments often used for this type of measurement normally use diffuse illumination or collimated illumination. These instruments are intended for traditional densitometry or colorimetry, which measure sample density, transmittance, or color directly. For example, the X-Rite DTP41™ spectrophotometer can do multiple spectral transmittance measurements automatically, but it only uses diffuse illumination for transmittance measurement. The GretagMacbeth SpectroScanT™ provides both diffuse and collimated illumination. The SpectroScanT provides automated reflection measurement. For transmittance measurement, it can only measure one color sample at a time.

Transmissive-Type vs. Reflective-Type

A key difference between the two types of projectors is that light passes through the sample twice in the reflective-type projectors as shown in Fig. 1 and 2. The effective transmittance of the same sample when projected by a transmissive-type projector is half of that when projected by a reflective-type projector. Because the distance between the mirror plane and the sample plane (the Fresnel lens is sandwiched in between) is not negligible, there can be significant amount of parallax, which will produce an effect similar to the optical dot gain.

Viewing Conditions

Another important aspect considered is that most overhead projection transparencies are used in environments where complete control of lighting is neither possible nor desired. There can be many forms of natural or artificial lightings, which can produce significant stray light on the projection screen. Stray light from the projector itself can also reach the projection screen and affect the final color calibration.

Spectroradiometric Measurement

In theory, overhead projection transparency color calibration measurement should be taken directly from the projected colors on the intended projection screen under the same conditions that the projection is intended to be viewed. Spot colorimetric or spectroradiometric measurement system can be used. The obstacle is that these types of measurement can be tedious and prone to human error if measured one at a time by hand when a large number of color samples need to be measured. Further, to compensate for illumination variation, the exact illumination at a certain location on the projection screen without transparency color sample needs to be measured immediately before or after the projected color measurement. It requires accurate repeatable instrument fixation.

Measurement Methods

To investigate the measurement problems for color calibration, we included 130 frequently used colors (Microsoft Windows™ palette colors) for business graphics and printed the colors on a transparency stock (11.50” x 8.50”) with a Lexmark C720™ color laser printer. We measured the spectral transmittance of the printed color samples with an Xrite DTP41™ spectrophotometer (diffuse illumination) and a GretagMacbeth SpectroScanT™ spec-trophotometer (both collimated and diffuse illumination). We then measured the colors projected by a 3M model 9100 projector™ (transmissive-type) and an Apollo model Cobra™ portable projector (reflective-type) in a “reality-simulated ” room with an automated spectroradiometric system.

Automated Spectroradiometric Measurement

We mounted a Photo Research PR650 spectroradiometer on a Meade™ astronomical telescope motorized tripod. The motorized tripod provides programmable pan and tilt motion to point the spectroradiometer to a desired location on the projection screen. The motion precision of the system and its mechanical capacity are sufficient for this application. The projection and measurement setup was carried out in a room with typical conference room settings. We did not try to block stray light from the projectors for this set of measurement because we intended to simulate normal projector use.

The essence of the automated measurement process is that colors will be sampled on a Cartesian grid. The number of sample rows and columns are variable inputs to the driving computer program. The motion system command set includes azimuth and altitude reports, so the sample locations are registered by having the operator successively align the PR650 on each of the four corner samples. The software will compensate for tilt and keystone but not pincushion distortion, so samples must be large enough to tolerate some misalignment. At a distance of 10 feet, the PR650 measures a patch about 3 inches in diameter, and patches that project to a diameter of 6 inches accommodate pincushion misregistration.

After a sheet of samples is measured, the same sample points are re-measured without the sheet to account for illumination non-uniformity across the projection screen.

Sample Scattering and Stray Light Verification Measurement

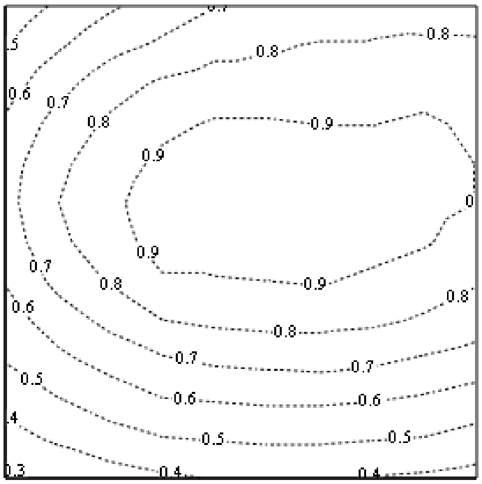
To verify the contribution of sample scattering, we measured some colors printed by both the laser printer and an inkjet printer (Lexmark J110™). To verify the contribution of stray light, we measured some colors manually with all stray light blocked except light from single color patch itself.

Measurement Results

Sample Illumination Non-Uniformity

The non-uniformity of both the projectors are obvious as shown in Fig. 3 (a) and (b). The non-uniformity data were measurements of 130 locations on the projection screen when the projector was on but with no transparency sheet in place.

a) Intensity Distribution of the 3M 9100 Projector



b) Intensity Distribution of the Apollo Projector

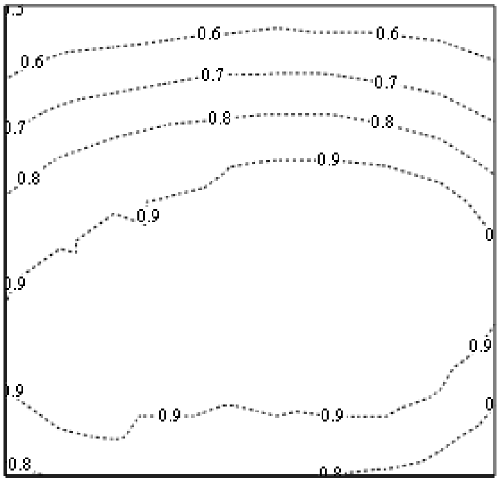


Figure 3. Light intensity distributions of the two overhead projectors. The scale of contour lines is a ratio of the illumination intensity at the corresponding location to that at the center of the screen.

Xrite-DTP41 vs. GretagMacbeth SpectroScanT

Both the instruments are capable of transmittance measurement in addition to their more often used reflection sample measurement capability. DTP41 is also capable of automated multiple transmittance measurements while the SpectoScanT is not able to perform automated transmittance measurement. The DTP41 only provides diffuse illumination while the SpectroScanT provides both diffuse and collimated illumination. Here we compare the results by the two instruments with diffuse illumination. For the 130 color samples, the two instruments provide reasonable consistent results with an average difference of 0.2% and a standard deviation of 1.2% for all wavelengths and samples. The largest possible color difference is estimated to be about 4 CIELAB if projected. As we stated earlier, transmittance data with diffuse illumination may not represent the projected colors. Here the comparison shows good measurement agreement can be achieved as long as the same illumination and measurement geometry are used.

Diffuse Illumination vs. Collimated Illumination

Because the SpectroScanT allows options of both diffuse illumination and collimated illumination, we used both illuminations to measure the spectral transmittances of the 130 colors for comparison. Fig.4 shows the average ratio at each wavelength for all 130 samples. The error bars represent the 95% intervals.

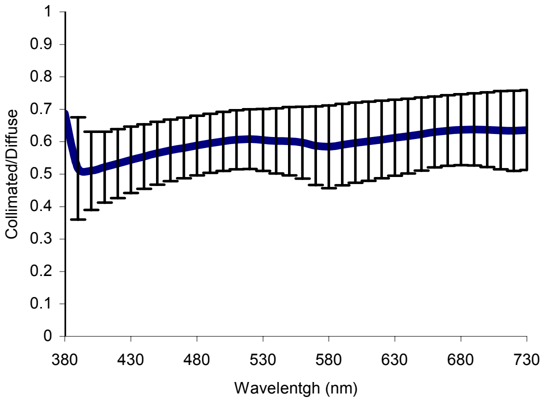


Figure 4 The average ratios of spectral transmittance measured using collimated illumination to that measured with diffuse illumination of all 130 samples. The error bars represent the 95% confidence intervals.

Projection Equivalent Transmittance

We measured the projected colors using the automated PR-650 measurement system. The measurements were done for both the 3M 9100 and the Apollo Cobra projector. As mentioned above, because of the large illumination variation across the projection screen, we divided the measured spectro-irradiance by that measured without the transparency print. The resulted ratio is a quantity that is equivalent to spectral transmittances measured on the projection screen and therefore is related to the true projected color with an ideal uniform projector. We thereafter call this quantity as the equivalent transmittance.

Fig. 5 (a) – (c) shows typical cases of equivalent transmittance versus that measured with collimated and diffuse illumination.

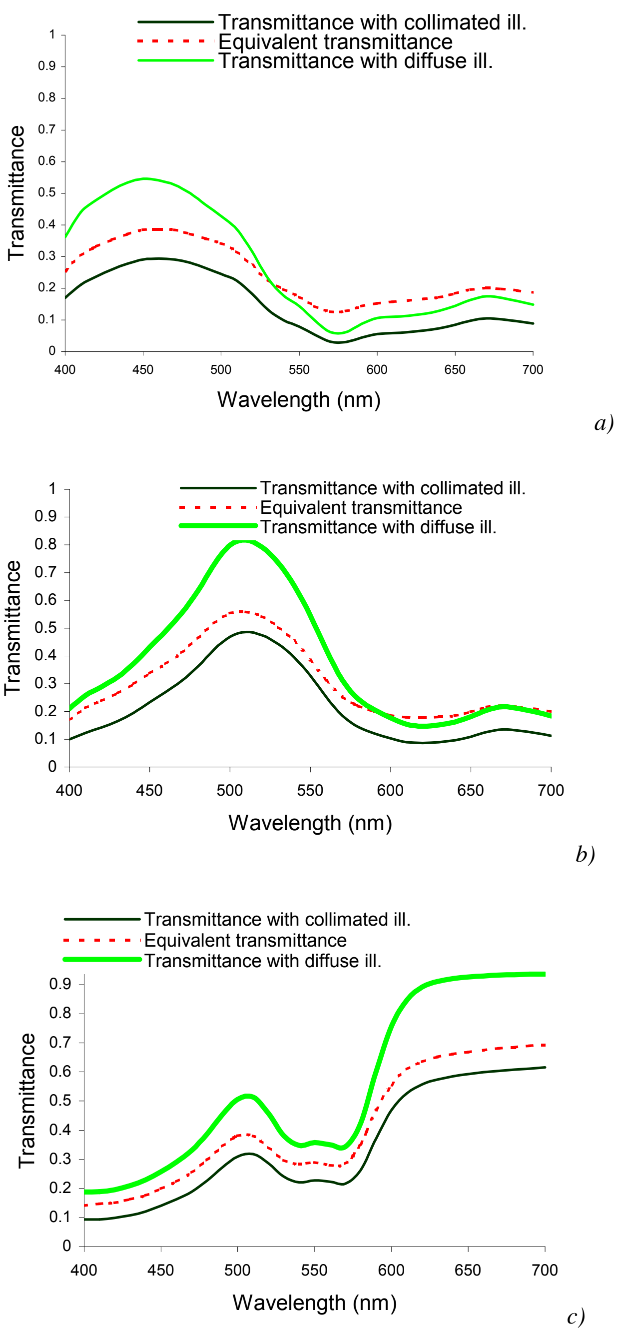


Figure 5. a)-c) Comparison of the equivalent spectral transmittance with transmittances measured with collimated and diffuse illumination, respectively, of three different printed transparency colors.

Comparison of EP and Inkjet Scattering

Figure 6 shows the differences of equivalent transmittance and that measured with diffuse illumination of the 100% cyan color samples printed by the laser printer and the inkjet printer, respectively.

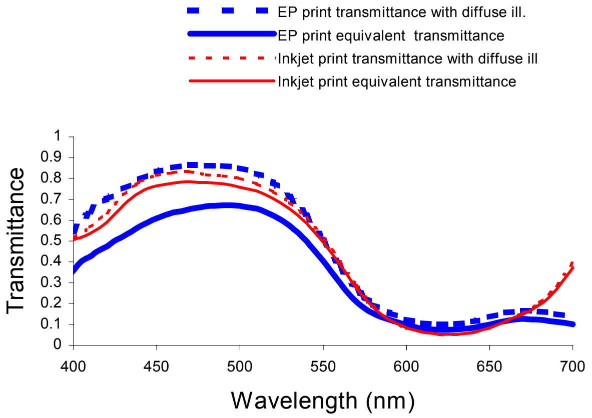


Figure 6. Comparison of measured equivalent transmittance and that measured with diffuse illumination of the 100% cyan color samples printed by an EP printer and an inkjet printer, respectively. Thicker lines represent the laser print sample; thinner line, the inkjet print sample.

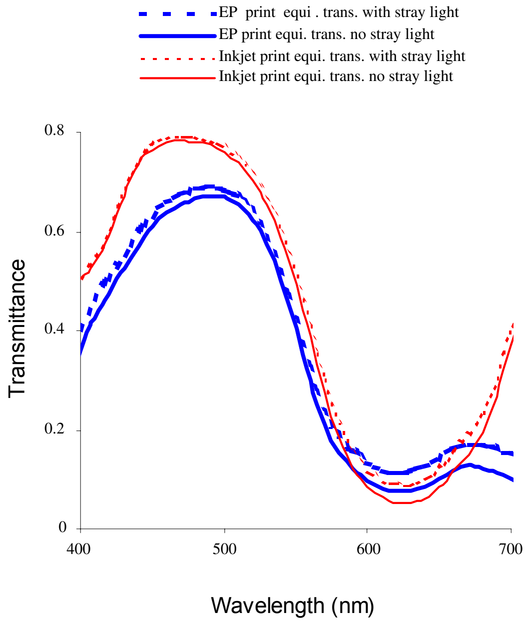


Figure 7. Contribution of stray light to the equivalent transmittance of the 100% cyan color sample. Thicker lines represent the laser print sample; the thinner line the inkjet print sample.

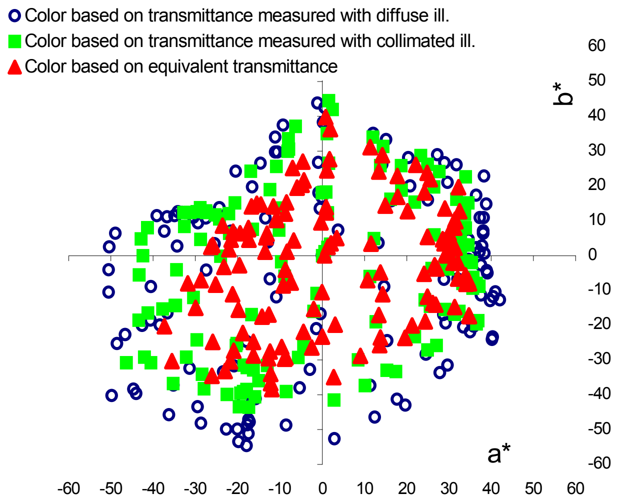


Figure 8.Computed projected colors by a transmissive-type projector based on transmittance data (diffuse illumination, collimated illumination, and equivalent transmittance).

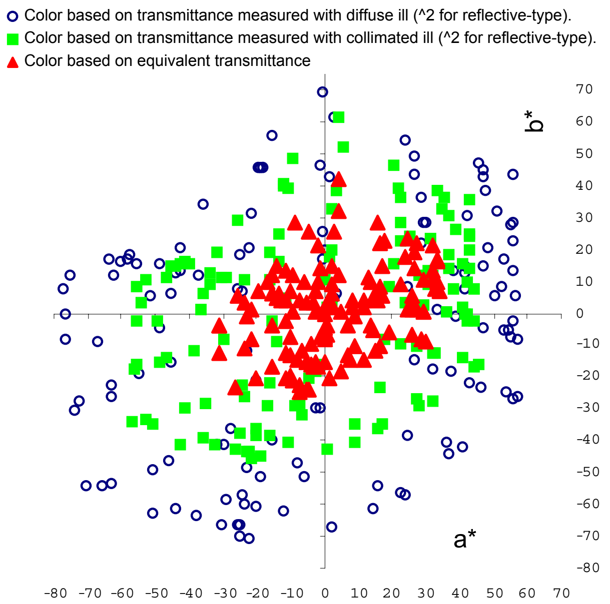


Figure 9.Computed projected colors by a reflective-type projector based on transmittance data(diffuse illumination, collimated illumination, and equivalent transmittance). The transmittance data measured with diffuse and collimated illumination are raised to the power of 2 to simulate the double-pass configuration of the reflective-type projectors.

Influence of Measurement Errors on the Final Projection Color Calibration

If the directly measured transmittance data with diffuse illumination are used to perform color calibration for a EP printer, the calibration is essentially performed for viewing the transparency print on a back-illuminated transparency viewer. When the print is projected on the screen, the colors, in general, will be less saturated as compared to that of an equivalent transparency print with no or little scattering.

The effect of scattering and stray light will essentially “shrink” the effective gamut of the printer. With the three sets of measured transmittance data (diffuse illumination, collimated illumination, and equivalent transmittance), we can compute and compare the corresponding projected color to show the gamut differences. Fig. 8 shows the computed projected colors when projected with a transmissive-type projector, the CIE illuminant A, and a perfect white screen. Similarly, Fig. 9 shows the computed colors with a reflective-type projector. Because light passes the samples twice in the reflective-type projector, the transmittance measured with diffuse and collimated illumination are raised to the power of two for valid comparison.

Discussion

The process of overhead projection transparency color calibration involves many contributing factors and variables. A better understanding of these factors will help to improve the calibration. Fig.3 shows that regular off the shelf projectors have a severe illumination non-uniformity problem. Such large non-uniformity is rather large from a colorimetric perspective. However, it seems that the visual system adapts well to illumination variation. Fig.4 shows that for the SpectroScanT, transmittance measured with collimated illumination differ greatly from that measured with diffuse illumination for EP print samples. The large 95% variation intervals indicate that the difference between two transmittances is sample dependent. As can be expected, different color patches may have different toner surface structures depending on the specific toner area coverage, toner thickness, and halftoning.

Fig. 5 a) to c) shows the equivalent transmittance versus that measured with collimated and diffuse illumination of three typical colors. The trend indicates that the equivalent transmittance which describes light reaching the final image point on the screen should be measured with a special state of illumination somewhere in between the diffuse and the collimated. The diverging angle of the illumination beam is determined by the ratio of the dimension of the lamp (including the reflector) image at the first principal point of the projection lens (or the diameter of the projection lens whichever is smaller) to the distance between the projection lens and the sample plane. Due to stray light, as shown in Fig. 5 a) and b), the equivalent transmittances at some wavelengths (low transmittances) are even higher than that measured with diffuse illumination. Fig. 6 and 7 further show the contribution of scattering and stray light with comparisons between EP color samples and Inkjet color samples.

Scattering and stray light can significantly affect the projected colors as shown in Fig. 8 and 9. EP overhead projection transparency color calibration based on sample transmittance data measured with diffuse illumination will produce projected color appearing to be washed out. Fig. 10

shows that the color gamut boundary can be significantly increased if the toner or ink thickness is doubled. That is because the 130 colors were printed according to reflective print color calibration. In the case of reflective print samples, light passes the toner or ink layer twice with the paper substrate serving as the diffuse reflective "mirror". In Fig. 9, the colors derived based on transmittance with collimated illumination have a much larger gamut boundary than that of the equivalent transmittance, which can be partially attributed to stray light. Because the brightness of the projected colors by the reflective-type projector examined here is less as compared to that projected by the transmissive-type projector, stray light reduce the gamut more severely. Further, because there is a significant parallax caused by the distance between the sample plane and the mirror reflecting surface, as shown in Fig. 2, light entering the sample may not be able to re-enter the sample from the bottom, which will create severe light leakage. Alternatively, light that does not pass through the sample may bounce off the mirror and enter the sample from the bottom. Such light leaking will introduce another form of stray light that can affect the projected color depending on the dimension of the color sample projected. This form of stray light is even more difficult to control and characterize and will further reduce the gamut.

Conclusions

We analyzed many factors that can affect projection transparency color calibration. Some factors are difficult to control and characterize. For good color calibration, final projected colors should be measured directly. Using transmittance data measured with spectrophotometers to perform overhead projection transparency calibration will introduce large measurement bias for samples of significant optical scattering such as EP transparency print. The parallax design limitation of the reflective-type projectors makes it difficult to predict final projected colors with transmittance measured directly with the sample, leaving measuring the projected colors the only solution. We further reported an automated spectro-irradiance measurement system to accomplish the many projected color measurement automatically.

Acknowledgement

We would like to thank Mr. Scottie Franklin at Lexmark International Inc. for assisting some of the measurements.

References

1. C. Cui, Dependence of color hue-shift on ink and toner scattering power, IS&T NIP16, 2000, Vancouver, B.C. Canada, P574-577.
2. H. Mizes, Predictive modeling of color projection quality II – Surface roughness effects on transparency projection efficiency, IS&T, 1997, P. 350-353.

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, digital color imaging, color science, computer color formulation and psychophysics.