Device Independent Color Measurement: Transforming Gretag Measurement Data into Simulated X-Rite Data

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Abstract

Measurements of samples made by two or more spectrocolorimeters, even when made with what the manufacturer certifies as identical instruments, usually do not agree. One source of such disagreements is differences in the physical makeup of the instruments. The optics, physical structure, light sources, spectral analyzers, and detectors of two instruments are never exactly the same. A second source is the interaction of optical characteristics of the sample (e.g., translucency) with the optical configuration of the instrument. In particular, measurement of small areas, such as slightly translucent print control strips, can highlight the problems of measurement disagreement.

Measurements of slightly translucent white samples made with two of the commonly used portable instruments, the Gretag SPM series and the X-Rite model 938, often exhibit significant differences. This paper details application to graphic arts measurements of an experimental method of reducing errors caused by interaction of highly translucent plastic samples with instrument geometry. In particular, the work reported here investigates the use this method to modify data taken with a Gretag instrument to make it agree more closely with data taken with an X-Rite instrument.

The conclusion of this investigation is that while this method can do a partial correction for differences caused by the interaction of moderately translucent samples with the instruments, the level of uncertainty in measurement data for nearly opaque samples caused by instrument noise, etc. makes its regular use somewhat questionable.

Introduction

At the 1994 Electronic Imaging conference, the author presented a paper[1] which questioned whether device independent color could be achieved using color measurement data which were modified by artifacts introduced by the measuring instruments. Differences of one CLab* ΔE or greater between measurements of the same sample set made with different instruments are commonly observed[2]. The use of calibrated color standard plaques (e.g., NPL calibrated BCRA tiles) in conjunction with the software used with most of the currently marketed spectrocolorimeters makes it possible to modify data from instruments of different design and manufacture to produce similar color values when measuring colored samples which have translucencies similar to those of the plaques set used for calibration. Properly used, measurements of these color standards allow most instrument wavelength errors to be corrected. However, the use of these standards does not allow for correction of photometric errors caused by the interaction of the instrument illumination and viewing apertures with samples of various translucencies.

During the past six years the author has presented seven papers on various aspects of lateral diffusion error, (LDE) (a.k.a. edge-loss error[3], translucency error[4], and translucent blurring error[5]). LDE is caused by the failure of the instrument to see all of the light reflected by a translucent sample. In general, this error is larger when samples of greater translucency are measured. The first three papers [6,7,8] that the author published on this subject introduced the LDE mechanism to the members of TAGA.

In this work, the LDE of each sample was determined by measuring the sample with a 45/0 geometry instrument with a fixed viewing area and several illumination aperture areas. The instrument used for these measurements was the Byk-Gardner Color Machine (BGCM). This instrument has a viewing area set by the optics of the detector channel. The illumination area is set by an aperture plate that is contact with the sample. The BGCM was suppled with auxiliary detector optics that gave a 6 mm diameter viewing area. The 31 mm diameter aperture plate supplied with the instrument normally is used to define the illumination area. Our machinist made several additional aperture plates which allowed measurements to be made with illumination areas as small as 6 mm diameter. The measurement data was presented as plots of aperture size vs. CLab color difference relative to the 31mm diameter aperture color measurement.

The first data taken with this apparatus was presented in summary in a 1991 unpublished white paper prepared for the Committee for Graphic Arts Technical Standards (CGATS). This paper compared several aperture size averaged color differences of a set of color plaques with measurements made with two portable instruments. At the time of the preparation the white paper and the subsequent presentation of the three papers to TAGA, the only know way of overcoming this problem was the use of instruments with a large illumination aperture and a small viewing aperture or vice-versa.

Background

The idea that there might be a practical way to correct for LDE came around the time of the presentation of a paper[9] by the author at the 1995 Electronic Imaging Conference. This paper explored the use of standard fluorescent plaques as a means of qualitatively determining measurement error caused by sample fluorescence. If it was possible to use plaques with known fluorescent properties to determine instrument errors caused by fluorescent samples, it was reasoned that the use of standards with known translucency might determine the LDE characteristics of instruments. A paper[10] presented at the 1995 TAGA explored this possibility.

The translucency standards measured for that paper were supplied by Professor Simon at Clemson University[11]. (Professor Simon also supplied the fluorescent plaques used for data for the EI paper.) These plaques, which were approximately 50 mm square and 3 mm thick, ranged in over-black-over-white contrast ratio from 0.50 to 0.99. Unfortunately, they were all too translucent to test the use of standards for determining instrument LDE values. However, in the course of making measurements, another property of 45/0 geometry instruments was discovered. The paper primarily dealt with detailing this property and the possibility of developing a method for correcting for LDE using this instrument property.

As a sample is moved away from the port of instruments which employ annular 45° illumination (e.g., the BGCM), the area illuminated increases and the edge of the illuminated area begins to dim. When the sample is at a distance of about one quarter of the illumination aperture diameter, there is a noticeable bright spot in the center of the lighted area. As the sample is moved further away, this bright spot decreases in diameter and the diameter of the dimly illuminated area increases. When the sample is at a distance of about one-half the aperture diameter, this bright spot disappears. With further movement, a dark spot develops at the center. When the sample is brought to a distance of about the aperture diameter, this dark spot is approximately the same diameter as the aperture. These patterns can be readily observed by placing a piece of tablet paper on the instrument port and slowly moving away from the port.

If the sample is nearly opaque (i.e., having very low translucency), the edges of this dark spot will be very distinct. When the sample is translucent, these edges are less distinct and a slight lightness in the dark spot can be observed. This is the result of light laterally diffusing from the lighted area into the dark spot. A measurement of this dark area is proportional to the LDE.

Figure 1 is a reproduction of figure 4 from the 1995 TAGA paper. It is the 600 nm spectral reflectance obtained from the BGCM setup with 4 mm diameter illumination and 3 mm diameter viewing areas. The three samples are a highly opaque chrome green plastic plaque (GREEN 39) and two translucency plaques measured over a black backing. The data for each sample was normalized by its on port value.

The vertical separation between the curve of the opaque Green 39 curve at, say, 2 mm displacement and that of the curve for the more translucent sample, 75OB, is greater than that of the curve for the less translucent sample, 85OB. Indeed, when this displacement at 2 mm distance is plotted against the rLDE (i.e., LDE in per cent reflectance divided by the reflectance measured with 31 mm illumination), a monotonically increasing curve results. The TAGA paper contains such plots for three illumination-viewing aperture combinations—the BGCM with 4 and 8 mm illumination with 3 mm viewing and the ACS-500 portable instrument (an OEM version of the Gretag SPM-100 which has a nominal 45° incident illumination 2.8 mm in diameter and a 3.5 mm diameter viewing area). All three curves are the same shape, but with some displacement from one another.

This port offset measurement method appeared to give a means of determining LDE for an instrument without equipping it with two or more illumination sizes (something that is not practical to do on such instruments as the Gretag SPM). In a paper[12] presented at a SPE meeting in St. Louis, the author described implementation of this method for correcting LDE. In this work, samples of various translucencies were measured with the BGCM equipped with a 4mm diameter illumination aperture and a 3mm diameter viewing aperture (hereafter termed a 4/3 configuration). This data was compared to measurement data taken with the instrument equipped with a 38 mm diameter illumination aperture and a 3 mm diameter viewing aperture (hereafter termed a 38/3 configuration) and the LDE for each sample was calculated. Next, a series of measurements was made using the 4/3 configuration with the samples moved back from the instrument port. Reflectance data from seven white samples of varying translucencies was then used to fit a function to 600 nm wavelength on-port and off-port measurements to the rLDE of the seven samples. This function was then used to derive LDE corrected values for 4/3 measurements of 14 colored samples. The LDE corrected values for these samples were then compared to the 38/3 measurements of the samples. This correction procedure reduced the CLab color differences between the 4/3 and 38/3 data by 75% or more.

Measurement Study Design

The present study aimed to experimentally determine two functions which will allow measurements made by one small aperture (e.g., portable) instrument to be transformed into data that will correlate better to those made by another instrument. One of the needed functions relates the on-port/off-port measurements of several calibration samples made by one instrument to the corresponding rLDE. A second function is needed to relate the sample specific set of rLDE values for one instrument to a similar set of rLDE values for a second instrument.

Since many instruments cannot be readily fitted with a very large aperture, the BGCM is used to get the large aperture reference measurements needed to determine the portable instrument LDE values for each of the several translucent calibration samples used. Usual practice in most measurement correlation studies is to calibrate each instrument with its own white calibration plaque. However, since one of the measurements for determining each LDE value is made with the candidate instrument and the other is made with the large aperture BGCM, all of the instruments need to be related to a common calibration base. This is accomplished by measuring a low translucency white sample with each instrument and using this data to adjust all other measured values to a common base.

Once these LDE values have been determined, one or more of the instruments can be used to make one on-port and several off-port measurements of each of the calibration sample. Preparing plots, similar to those in figure 1, of these off-port measurements of all the calibration samples allows an off-port distance to be selected which will allow a function which relates the curve difference values to the rLDE of the samples. This provides all of the data needed to derive the two required functions.

Measurement

This paper is concerned with the relationship of measurement data from a Gretag instrument and a X-Rite instrument. The results are abstracted from data taken for a larger study involving five instruments: the BGCM, an OEM version of the Gretag SPM-100, a X-Rite 938, a X-Rite DTP22, and a Colortron II. As noted before, the BGCM is a bench instrument with multiple illumination apertures. The other four instruments are handheld portable instruments. A previous project required the adaptation of each of these portable instrument to be positioned with a three-axis stage to automatically measure the patches on large calibration proofs to get color data for determining the digital transfer function of printers and scanners. Each of the four instruments is attached to a fixture that is part of a kinematic mounting system. Each fixture has three adjustable down-pointing ballpoint screw legs. The fixture is accurately positioned when these ballpoint screws engage three pads on a cradle attached to the vertical positioning drive of the three-axis stage. One of the three cradle pads has a conical hole in it; the second pad has a V-groove in it; the third pad is a flat surface. After the screws have been properly adjusted, the instrument containing fixture can be removed and reinstalled into the cradle without any change in the fixture position relative to the cradle frame.

When used with the 3-axis scanner, the cradle is lowered until the instrument fixture rest on the surface of the proof to be measured. When the cradle is lowered slightly more, a switch tripped which stops the downward travel of the cradle. This design effectively simulates the manual placement of the instrument on the proof.

For the measurement of samples in this study, the cradle was attached to the slider of a vertically mounted motor driven slide attached to a vertical structure mounted on an optical bench. A measurement was first made with the instrument resting on the sample. Then the instrument moved progressively upward with steps of approximately 50 μm (0.002") for the Gretag and Colortron and steps of 100 μm (0.004") for the X-Rite instruments. A total of 22 samples were measured with each of the four portable instruments. The samples were also measured with the BGCM using seven illumination aperture sizes. Part of the data reduction process involved referencing all of the measurement data to a pressed $BaSO_4$ plaque.

The resulting data was not as consistent as might be expected if the primary inter-instrument differences were due solely to LDE. Several causes of these inconsistencies were found. The samples were laid on a thick black card which was laying on the optical table. At one point in the measurement process it was observed that, dependent on the humidity of the room air, the card would curve upward or downward at times. The weight of the instrument and mounting fixture flattened the card and held the sample firmly against the instrument port when the zero displacement reading is taken. As the instrument was moved upward, the sample also moved upward. In later measurements, the card was replaced with black printed paper laying directly on the optical table.

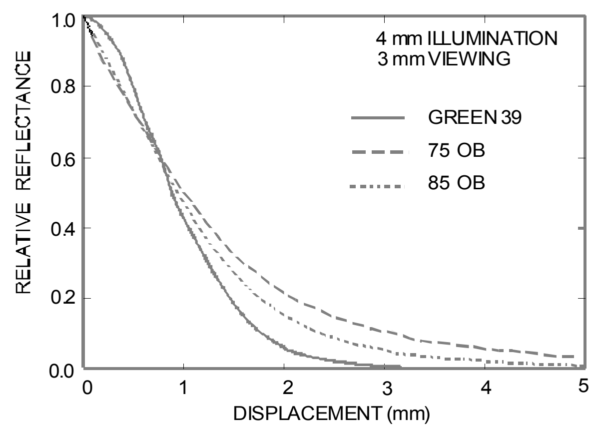

Figure 1.

The 45/0 and 0/45 geometry instruments are generally calibrated with glossy standards that very nearly exhibit Lambertian (cosine) scattering functions. Many samples measured by these instruments do not have the same angular scattering pattern as that of the instrument calibration standard. This nonstandard gonioreflectance function can come about from surface characteristics (e.g., gloss vs. matte), internal structure and reflectance of the sample. Most 45/0 and 0/45 geometry instruments are designed to measure standards and samples with a Lambertian scattering functions. Minor variations in the viewing or illumination angles and field of view can cause instruments to give different results for non-uniform scattering samples.

Approximate 10,000 reflectance spectra were logged. The portion of the data used for this paper was processed by multiple operations in a spreadsheet program. On occasion, when some points did not fall into line, re-processing of the data indicated that a mistake had been made in the original data reduction.

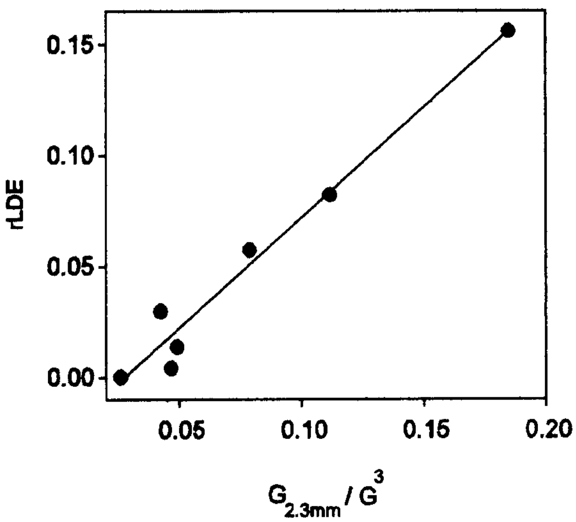

Figure 2

The BGCM and the Gretag SPM-100 employ 45/0 geometry; the X-Rite 938 employs 0/45 geometry. There has been some question as to whether the instrument geometry affects the measured value. At first examination, Helmholtz optical reciprocity would seem to indicate that the values should be the same, all other things being equal. However, a paper[13] presented at the 1993 TAGA meeting found that this was not the case. However, a paper[8] presented at TAGA in 1994 found that optical reciprocity does hold. A 1985 paper by Clarke and Perry[14] details the conditions which must hold if reciprocity is operational. In all probability, the Gretag and X-Rite meet the conditions necessary for optical reciprocity to work.

The ordinate of the plot in figure 2 is in units of rLDE. The plotted values were obtained from $BaSO_4$ adjusted 600 nm measurements of seven samples made with the BGCM large port and the Gretag. The abscissa is the ratio of Gretag 2.3 mm off-port values at 600 nm to the on-port values divided be the square of the on-port fractional reflectance (i.e., the fractional off-port reflectance divided by the cube of the fractional on-port reflectance).

Figure 3 gives the relationship between the Gretag rLDE and the X-Rite rLDE for the calibration samples.

Implementation

These relational functions were derived using data from a Gretag OEM version of the SPM-100, S/N 3253-10432, and an X-Rite Model 938, S/N 002594. No data is available to indicate if these functions are applicable to instruments other than these two instruments.

In order to use these functions to convert a Gretag measurement into a simulated X-Rite measurement, the following steps must be performed:

1. Measure the sample with the Gretag sitting on the sample surface (on-port measurement).
2. Measure the sample with the Gretag 2.3 mm above the sample surface (off-port measurement).
3. Divide the fractional off-port reflectance by the cube of the fractional on-port reflectance.
4. Use this resulting value to determine the rLDE (from the graph in figure 2).
5. Multiply the on-port reflectance by the BGCM $BaSO_4$ reflectance value and divide it by the Gretag $BaSO_4$ reflectance value (the result is the measured Gretag sample reflectance referenced to the BGCM).
6. Get the BGCM large aperture reflectance value by dividing the result (from step 5) by (1 - rLDE).
7. Using the Gretag rLDE and the graph from figure 3, get the X-Rite rLDE.
8. Multiply the BGCM large aperture reflectance value (from step 6) by the X-Rite rLDE and subtract it from the BGCM value. This is the BGCM referenced X-Rite value including the X-Rite LDE.
9. Multiply the result by the X-Rite $BaSO_4$ reflectance value and divide the result by the BGCM $BaSO_4$ value. This is the simulated X-Rite reflectance value derived from the Gretag measurement.

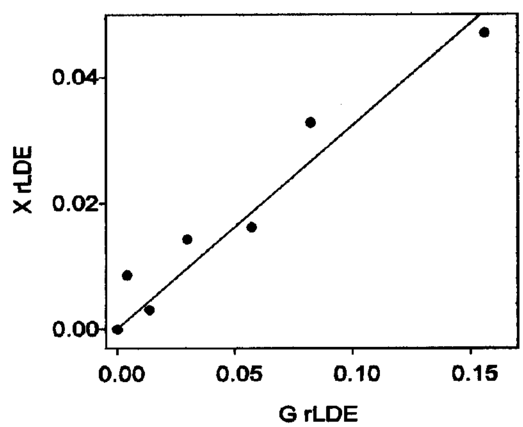

Figure 3

TABLE I

Sample	X	G	Xs	|ΔR|	|ΔRs|
Grey	61.58	60.77	61.87	0.81	0.29
Yellow	77.68	73.13	75.77	4.55	1.91
Orange	68.55	65.12	69.04	3.43	0.49

Table I shows the reflectance values for three BCRA tiles. The columns headed X and G contain the 600nm wavelength reflectance values measured with the X-Rite 938 and the Gretag SPM-100. The column headed Xs shows the X-Rite simulated value derived from the Gretag measurements using the nine step conversion procedure. The column headed |ΔR| gives the absolute difference between the measured values while the column headed |ΔRs| contains the absolute difference between the X-Rite measured and simulated values.

Discussion

While the measurements of the samples at some distance from the instrument port usually correlates to the LDE, there is a problem of finding a workable method for interrelating measurements of samples with different reflectances and different translucencies to each other to develop a common database for calibration. In the work with plastic samples, the on-port/off-port ratios were derived by taking the ratio of the off-port measured value to the on-port value.

In the past, it has been observed that the LDE seems to have some relationship to the square of the reflectance. In the present work, the off-port/on-port ratio was divided by the square of the fractional reflectance to try to further eliminate the dependence of the function on calibration reflectance. The straight line relationship in figure 2 seems to indicate that this approach worked. However, it only works for samples with reflectances greater than 60% or so. When samples have low reflectance values, such is the case of reds, oranges, and yellows at short wavelengths, the cube of the on-port reflectance that is in the denominator of the ratio makes data unuseable.

While most portable instruments can be used to measure small areas on a proof, they do depend on a large flat area adjacent to the sample for supporting the instrument. When small, thick samples are measured with these instruments, the back end of the instrument must be supported with a block that is the same thickness as the sample. When measuring BCRA tiles, it is common practice to use one of the other tiles from the set to support the back end of the instrument. The BCRA tiles are not all the same thickness.

The Gretag SPM instruments have a measuring aperture that defines the area on the sample that is measured. The plate that contains this aperture is not the front support for the instrument. The front of the instrument is supported by two 10 × 20 mm pads located about 20 mm behind the aperture and 27 mm on each side of the instrument center line. When measuring 50 mm diameter plastic samples and the pressed $BaSO_4$ with the instrument, auxiliary support is required on each side of the front of the instrument as well as the back of the instrument. This was not recognized until it was observed that many of the measured values for small area samples did not track each other.

This method of correction depends on a change in measured value with movement of the sample from the port. Small sample offsets (e.g., 50 μm) from the port while making on-port measurements can cause changes (e.g., a few tenths of a per cent) in the measured value which affect the X-Rite simulated values. Noise and drift of a few tenth of a per cent add to the uncertainty of the simulated values.

Conclusions

With noise and positioning errors that may add up to as much as 0.5% uncertainty, this method is of doubtful usefulness for manipulating measurements of samples that have very low translucency. This excludes its use with most printing papers and graphic arts colors. However, with high gloss papers, plastic sheets, and red and yellow colorants, which are very transparent at long wavelengths, this method, when fully developed, may be of value.

The improvements in data values that have been achieved in the work with plastics and the present work are not as consistently good as might be expected. For this reason and the difficulty of making off-port measurements, the method is not ready for practical application.

Much of the problem of improving the results lays in finding a reliable method for interrelating data from samples of different reflectances. The Gretag SPM-100 with the positioning difficulty encountered with the measurement of small, thick samples, is probably not the best instrument for this purpose. The BGCM, which has a flat port and does a secondary standardization at the time of each measurement, is probably a better instrument to use for getting data for establishing an interrelationship. Once a reliable relationship is established, it should be applicable to use with other instruments.

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