EFFECT OF ADJACENT COLOR ON SAMPLE MEASURED COLOR

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ABSTRACT: The author presented a paper[1] at the 2000 TAGA annual meeting which demonstrated that colored areas adjacent to a white sample area can affect the measured value of the sample area. This paper reports on an extension of the previous work. Using samples prepared with improved techniques, the methods used in the previous paper have been refined and the differences caused by making measurements of the samples with both white and black backing have been determined. Also, the effects of replacing the white central area with other colors and/or reducing the saturation of the colors are reported. Results of another set of experiments show that the instrument position within the central area affects the measured color. Finally, it is shown that on occasion the color of the instrument aperture plate, which is placed against the sample while the measurement is being made, can affect the measured color.

BACKGROUND

The author submitted an abstract of a proposed paper for presentation at a 1999 meeting on the effects of surrounding color on color vision that the Inter-Society Color Council (ISCC) sponsored. The paper was accepted for presentation as a poster. The author declined to present the paper as a poster since he felt that it was most suitable for oral presentation. The abstract was subsequently submitted for possible presentation at the 2000 annual meeting of TAGA. The paper[1] was accepted and presented at the meeting held at Colorado Springs, CO, April 3, 2000.

The exhibits used in the study reported in this paper were prepared using a Hewlett-Packard inkjet printer and a number of inkjet specific receptor papers. One of the conclusions of the paper was that the inkjet results did not give data which was directly applicable to problems encountered when conventional prepress proofing and press run products are measured. In order to get data applicable to these problems, the paper suggested that further evaluation of the extent of this problem would require the preparation of exhibits using typical printing media and processes. While exhibits prepared with press runs would be ideal for this purpose, they were found to be prohibitively costly. Therefore, it was proposed that the use of exhibits made using some type of transfer prepress proofing system and a printing paper would produce more representative exhibits and useful data than was obtained in the study.

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REVIEW OF PREVIOUS WORK

In previous papers[3,4] which describe lateral diffusion error (LDE), the lateral diffusion of light within printing media was represented as a unidirectional diffusion of light from the area of the sample illuminated by the measuring instrument to the unilluminated area. Actually, after the light enters the sample, it diffuses in all directions. In this process, some small part of the light that diffuses out of the lighted area diffuses back into area viewed by the instrument.

Some of the laterally diffusing light propagates toward the top sample surface and some travels toward the bottom sample surface. Some portion also diffuses back into the illuminated area. There are a number of physical conditions which can affect the paths of the diffusing light and, thus, the LDE. For instance, if the area illuminated on the sample is equal to, or very nearly equal to, the sample size, then some laterally diffused light will exit through the sample edges. This will reduce the amount of light that re-diffuses back into the illuminated area and thus decrease the value of the measured reflectance. This type of light loss error was termed "edge-loss error" in a paper by Atkins and Billmeyer[2].

When any portion of the diffuse flux inside the sample encounters the sample surface, more than half may be reflected back into the sample. This will happen if the sample surface is smooth, such as is the case with coated or calendered hard finish paper. Figure 1 shows a representation of what happens when diffuse light encounters a sample/air interface. All light striking the surface at an incidence angle greater than about 42° relative to the surface normal, is totally reflected back into the sample. Some of this reflected light diffuses back into the area viewed by the instrument detector. If this reflection process did not occur, the lateral diffusion error would be even greater.

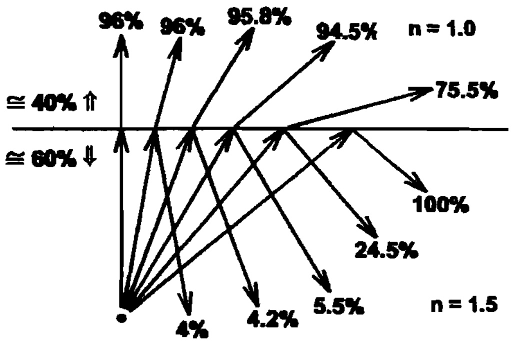

Figure 1 *When light passes through a surface, some is reflected by the surface. In the case of diffuse light going from a media with a refractive index of 1.5 (e.g. paper) to air (index of 1.0), about 60% of the light will be reflected back into the sample.*

What effect does a surface layer of ink have on this internal reflection ? First, there will be very little reflection at the interface between paper and the ink layer since they both have about the same index of refraction. However, at the interface between the ink surface and the air, a reflection pattern similar to that of figure 1 will be present. Ink is usually made up of a mixture of a vehicle and one or more pigments. The pigments in a colored ink will, at some wavelengths, absorb part of the light before and after it reflects off of the vehicle/air interface. In fact, at some wavelengths, little if any light will be reflected from the ink layer back into the paper. This lack of reflected light will decrease the amount of light that is re-diffused back into the area viewed by the instrument and thus increase the LDE at some wavelengths. This will show up as a small imprint of the ink spectrum on the measured reflection of the sample.

SAMPLE PREPARATION

The study reported at TAGA 2000 was designed to determine existence and magnitude of any color measurement errors caused by the presence of adjacent color areas. For these reasons, a limited number of sample targets (i.e. using cyan, magenta, and yellow surrounds) were printed on a variety of papers. These targets consisted of various diameter white areas (i.e. ink free areas) surrounded by a large areas of solid color. They were prepared using Corel WordPerfect Presentations graphics software, version 8, and printed with a HP model 855C inkjet printer. Unfortunately, the white areas on the targets turned out to be slightly elliptical because of a small software/printer scaling error. Also, there was minor ink splitter into the white areas with some colors. Since this was a preliminary study, these defects could be tolerated.

Often, when measurements of the targets were made using a handheld instrument, it was impossible to determine if the instrument was positioned exactly on the center of samples with the small white areas. To overcome this problem in the present study, it was decided to position the instrument on a x-y grid of points which covered the entire white target area. This sample scanning was performed with a three axis stage which progressively sets the instrument down at each of the desired x-y grid measurement positions. (This system is described on the author's website, www.rhometric.com.)

In the present study, the preparation of more dimensionally accurate targets was accomplished by making target templates using AutoCAD and then exporting them to a newer version of Corel WordPerfect Presentations (version 9). Various colors were then added to the templates and they were printed on inkjet photopaper with a new model HP 932C inkjet printer. Targets prepared using this method did not show any evidence of ink splitter when examined with a 9 power linen tester magnifier. On a second track, the target images were exported from the Presentations software in a TIF file format. These image files were then used to prepare digital transfer proofs on Warren LOE paper.

MEASUREMENT OBJECTIVES

The 2000 study demonstrated that the surrounding colors can affect measured color values. The present study was aimed at better defining the parameters of these effects. To that end, this program had the following objectives: a) refine the data relating the measurement error and diameter of the (white) target areas by using the improved exhibits and measurement techniques; b) determine if the color of the sample backing affects the error value; c) determine if errors are present when the circular target area is some color other than white; d) determine the effects of reducing the saturation of the colors used; e) determine if the position of the instrument within the circular sample area affects the error value; and f) determine if the color/texture of the bottom side the instrument aperture plate (i.e. the aim or sample positioning plate) can affect the measured value.

To achieve all but the last of these objectives, dimensionally accurate target templates with 4, 5, 6, 8, 10, 12, 15, and 20 mm diameter center target sections were prepared using AutoCAD. Various colors were then added to these templates using Presentations software. These targets were then printed on gloss inkjet photo paper (International Paper Jet-PRINT PHOTO™, Premium Photo Paper, Brilliant Gloss Finish) with the HP printer. This paper was selected because of its relatively high white reflectance and lack of trade mark printing on the back surface.

On a second track, the target images were exported from the Presentations software in a TIF file format. These image files were then used to prepare digital transfer proofs on Warren LOE paper.

A grid of points around the center of each of the targets was measured using an OEM version of the 45/0 geometry Gretag SPM-100 (which employs a 2.8mm diameter illumination and a 3.5mm diameter measuring area.) The grid used for measuring the four targets with the smallest center areas was 13x13 with a 0.040 inch (~1 mm) spacing. A 15x15 grid with 0.075 inch (~1.75mm) spacing was used for the four targets with the largest center areas. The measurement that represented the target center was selected from the 150+ measurements on the basis of the measurement coordinates and reflectance. From previous experience, it was know that the central of the target should have the highest reflectance at a wavelength at or near the maximum absorbance of the surrounding color.

MEASUREMENT RESULTS

Figure 2 (next page) shows plots of the target center reflectance of different diameter white targets surrounded by yellow. The specimens were backed with white paper. Note that in the long wavelength spectral region where yellow exhibits high reflectance (i.e. low absorbance), the curves for the samples and the white paper are tightly grouped. At short wavelengths where yellow has low reflectance (i.e. high absorbance), the curves separate according to diameter of the white areas.

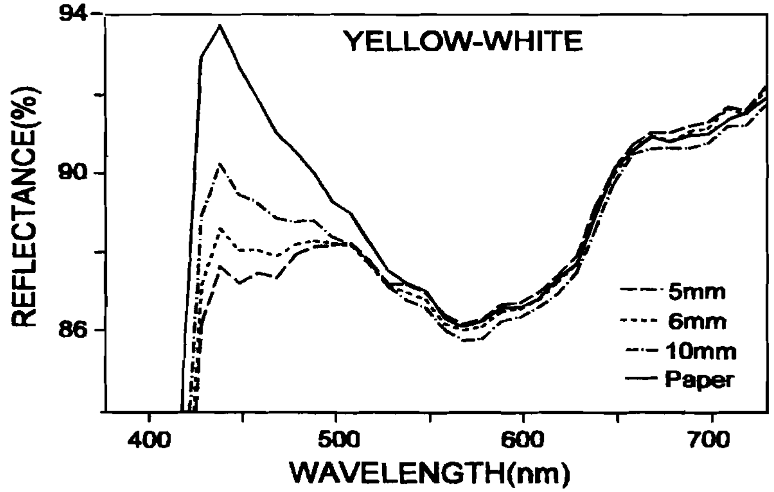

Figure 2 *Spectral reflectance plots comparing 5, 6, and 10mm diameter white paper areas surrounded by 100% yellow compared to paper with no surround.*

In this and the previous efforts, colored ink was always chosen for the sample surround. Black ink would also lower the reflectance of the white areas, but with a black surround, the surround effect can not be easily distinguished from random level errors in the measuring instrument or dark areas in the paper.

The 10mm curve (dot-dash line) in figure 2 gives an example of a level shift. This curve is consistently below all of the other curves at wavelengths longer than 550nm where the yellow surround has little effect.

In the previous paper, the D50-2° CLab* color difference between these center reflectance values and the reflectance of white paper not surrounded by any color were plotted against the diameter of the white target. Figure 3 is a plot of the color differences for the over-white measurement data displayed in figure 2 along with color differences obtained when the targets were measured with a black backing. These

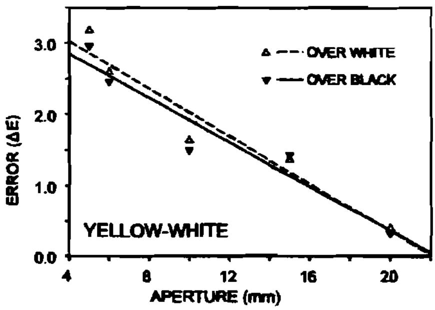

Figure 3 *Linear functions that relate the color differences to diameter of the white sample areas.*

two sets of measurements were used to derive linear regression functions that relate the color differences to the diameter of the white areas on the targets. These functions are plotted as straight lines on figure 3. Note that the color differences of the two measurement sets are essentially the same values. While the measured reflectance of the white paper and the targets are affected by the color of the backing, the color differences between white paper and white surrounded by color appear to be independent of the sample backing used while making the measurements of the set of samples. Note that some of the measured color difference points are above the regression lines and some are below the lines. Even so, the over-white and over-black measurement points for each target white area diameter track very closely. In fact, their distance from each other is much less than their distances from the regression lines. This would seem to indicate that a large part of the scatter of the points is due to differences in the color of the individual paper sheets that existed prior to printing of the targets. This possibility was considered when the targets were designed and provision was made for measuring the target areas on the paper sheets prior to printing. However, this pre-scanning feature was not used in the present work.

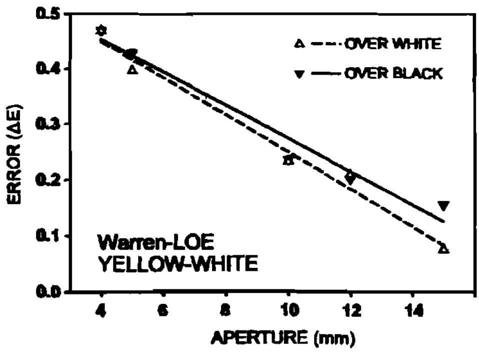

Figure 4 *Linear functions that relate the color differences to diameter of the white sample areas on Warren-LOE paper.*

The translucency of the inkjet glossy photo paper emphasized the surround color effect. While papers with similar translucencies are used in some prepress proofing systems, the photo paper is not representative of most printing papers. Figure 4 shows plots of regression lines similar to those of figure 3 for digital proofs prepared on Warren-LOE (i.e. targets with yellow surround and white centers). These targets were measured with both black and white backings. While the range of color differences for these targets is considerably less than that of the photo paper targets, the tracking of the over-white, over-black measurements is readily apparent.

The surrounding color affects the measured color of an included white area. Does the surrounding color affect the measured value of an included colored area ? How does the saturation of the colors affect the measured colors ? Figure 5 (next page) plots data derived from photo paper targets measured with white backing. The upper line is the color difference regression line for a 100% yellow center area surrounded by 100% cyan. The lower line is derived from a target with a 50% yellow center and 50% surrounding cyan. Lower color saturation reduces the measurement errors caused by surrounding color.

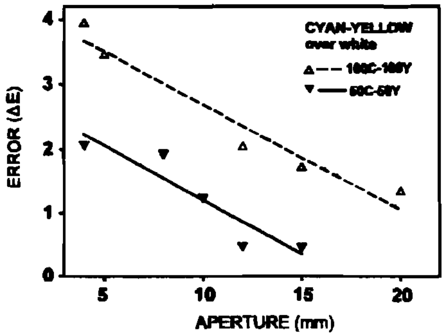

Figure 5 *A cyan surround can affect the measured color of an adjacent yellow areas.*

Will the instrument measuring position relative to the surrounding color affect measured value of the included color ? Obviously, if instrument is positioned so that some portion of the surrounding color is viewed by the detection system, the measured value will be affected. But what if the instrument is moved near the edge of the center area without viewing or illuminating any of the surrounding colored area ? The table below shows how instrument position affects the color measurement. In particular, this is the color differences measured when the instrument is moved away

OFFSET FROM CENTER	-2mm	-1mm	0	+1mm	+2mm
CLab*ΔE	0.99	0.39	0.0	0.11	0.92

from the center of the target by one and two millimeters in each direction. The target used was photo paper with an 8mm white area surrounded by 100% magenta. At 2mm instrument displacement from the center, the 3.5mm diameter instrument viewing aperture does not include any of the surround color. For reference, the center color measurement is approximately 2.8 CLab* ΔE different from the value of paper that is not adjacent to any color. The slight lack of symmetry between the positive and negative offset measurements is likely due to combined instrument measurement and positioning uncertainty.

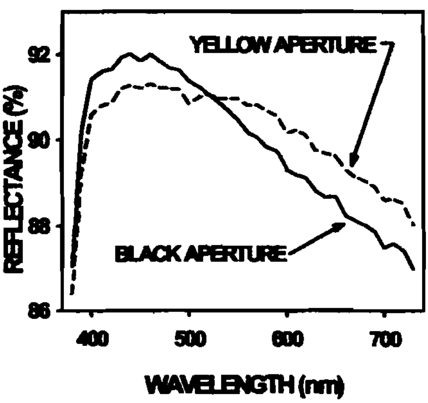

Figure 6 *Comparison of measurements of Russian Opal with black and yellow apertures in contact with sample surface.*

If an ink layer near the area being measured can affect the measured value, can the instrument aperture plate, which is in contact with the sample surface immediately adjacent to the measured area, affect the measured value ? To find out, measurements of ten samples with black and/or white backing were made with the Gretag in the normal manner. Then measurements were made with white, cyan, magenta, and yellow label stock with 4mm holes affixed to the bottom side of the instrument aperture. The labels were placed so that the edges of the holes did not obstruct the 3.5mm instrument aperture. The instrument was calibrated with the colored label in place prior to making each set of measurements. Figure 6 (previous page) shows a comparison of reflectance curves of glossy surface Russian opal obtained with black and yellow apertures in contact with the sample. Note that at long wavelengths, where yellow has high reflectance, the yellow curve is above the black curve. Figure 7 shows a smoothed data plot of the difference between the two curve in figure 6. The characteristic curve shape of yellow is quite apparent.

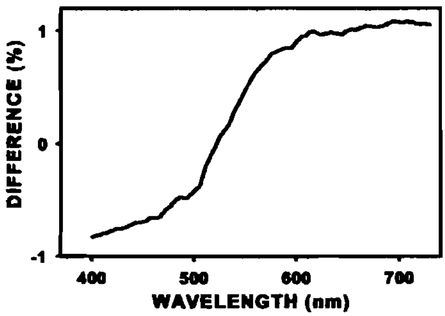

Figure 7 *Difference between the two curves in figure 6 (smoothed data).*

Four of the samples were measured both with black and white backing. Thus, fourteen sample combinations were measured with each of five aperture colors for a total of 70 measurements. The CLab* color differences between each colored aperture measurement and the corresponding black aperture values were then calculated. The black and yellow Russian opal measurements had a 0.85 CLab* ΔE. The color differences had a wide range of values running from a minimum of 0.08 ΔE to a maximum of 1.59 ΔE. The average of the color differences for the 56 measurement pairs 0.41 ΔE.

DISCUSSION

The wide variation in the color differences caused by the coloring of the underside of the instrument aperture which was in contact with the sample can be, in part, attributed to a number of known factors. As noted, the instrument was calibrated each time prior to making the measurements with the colored label in place. Once the calibration is performed, the measured value of the calibration standard should agree with any other measurement of the standard made with any other aperture color after calibration has been performed. Measurements made with the properly calibrated instrument equipped with apertures of two or more colors will probably agree if the color and translucency of the sample is similar to that of the calibration standard. If the translucency of the sample is greater than that of the standard (e.g. Russian opal), the light will laterally diffuse a greater distance from the aperture edge and thus be affected differently by the colored layer which is in contact with the sample surface. This will change the amount of the light that is re-diffused into the area viewed by the instrument.

This scenario assumes that the colored layer is in direct contact (i.e. optically coupled) with the top of the sample in much same way that ink is optically coupled to the underlying media (e.g. paper). To attain such coupling, the surfaces of the sample and the colored layer must be very smooth and flat or physically compliant. The amount of pressure applied during the measurement process can, in most cases, affect the degree of coupling. If the surface of the colored layer and/or the sample are rough or porous, then the coupling will be reduced and the effect of the aperture with colored underside on the measured value will be lessened. This would be the case with textile samples and some samples of uncoated paper.

When there is color on the underside of the instrument aperture, the surrounding color effectively moves as the instrument is moved and the relationship of the surround color to the instrument measuring area is always the same. As noted before, when the instrument is moved about in a central area surround by a colored ink area, the effect of the surrounding color will vary. Changes of pressure on the instrument aperture from one measurement position to the next may cause some additional changes in the measurement results.

Usually, when a sample is measured over a black backing, the LDE is less than when it is measured over a white backing[3]. As noted, the effects of surrounding color on measured color is a result lateral diffusion of light within the sample. Therefore, the near coincidence of the surround color effects for measurements made with the samples backed by black and white, as illustrated in figures 3 & 4, at first does not seem to make sense. In deed, the reflectance of the white paper measured over black with no surround is less than a measurement made with white backing. The same is true for measurements of each of the samples with white areas surrounded by color.

The conversion of the reflectances to the CIE tristimulus values is done by a linear process. This results in the differences between the tristimulus values for unsurrounded white compared to surrounded white being less for measurements made over black than for measurements made over white. The conversion of the tristimulus vales to CLab* color coordinates is accomplished by a non-linear process. This process skews the color values for the individual measurements relative to tristimulus values in such a way that the over-black and corresponding over-white color differences become almost identical.

Note that this surround color effect is a second order aspect of lateral diffusion error. Most of the LDE results from the lateral diffusion of light out of the illuminated area into the unilluminated area. Some small portion of the outward bound light flux is scattered back into the illuminated area and thus reduces, by a small amount, the LDE caused by the outward flux escape. The measurement error caused by the surrounding color is the result of a modification of this small returning flux. Errors caused by surrounding color are indicators of the presence of a much larger LDE. However, the lack of any error caused by surrounding color does not infer that there is no LDE.

One of the common steps in determining the transfer function of digital printing and scanning systems involves the measurement of targets with 100 or more (e.g. up to several thousand) colored areas. In the interest of reducing the target size, the squares on these targets are made relatively small and are measured with instruments with small apertures (e.g. the Gretag Spectrolino with 2.8mm illumination and 4.2mm viewing). If the target is designed so that the squares adjacent to the square being measured are only slightly different colors, the errors caused by surrounding colors would be virtually eliminated. However, this scheme would not eliminate the LDE caused by inadequate differences in the viewing and illumination apertures (e.g. Figure 7 and Table I of a 1993 TAGA paper[4] shows the magnitude of LDE in yellow sample measurements made with an instrument using 4mm illumination and 3mm viewing).

In papers presented at the 1999 TAGA meeting[5] and the 2000 meeting of the SPE Color & Appearance division[6], the author described a method for deriving the value of the LDE from measurements of the spatial distribution of the light reflected from the sample surface. This method is applicable for 45/0 and diffuse measurement geometries. At the time of the development of this method, the author was not aware of the problems of surrounding color, measurement position, and aperture plate color. Since these problems are another aspect of errors caused by lateral diffusion, it seems reasonable to assume that this correction method is applicable to correct errors caused by surrounding color.

CONCLUSIONS

As first demonstrated in the 2000 TAGA paper, colored areas surrounding a measured area can affect the measured value of the area. In addition to this, the position in the central (i.e. surrounded) area at which the measurement is made can affect the measured value. Also, the color of the instrument aperture plate which is in contact with the sample can affect the measured color.

These effects are the result of modification of the light that laterally diffuses into the instrument view from the surrounding colored area. Typically, the light that is in the surround is light that has laterally diffused out of the area illuminated by the instrument into the surrounding area. LDE, which is caused by a net outward diffusion of light will always be larger than the errors caused by the surrounding color effects.

There is an instrumental/software configuration which can correct for lateral diffusion errors and potentially surround color induced errors.

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