MODIFIED COLORIMETRIC METHODS FOR THE GRAPHIC ARTS

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Abstract: Current colorimetric methods are suitable in many industries for measuring and specifying the color of objects such as paper, paints and fabrics. However, the needs of the graphic arts and photography, where color pictures must be reproduced from only 3 or 4 transparent colorants, are quite different.

This paper shows how colorimetry can be used in the graphic arts from the standpoint of one experienced in both densitometry and colorimetry. Each system has advantages and disadvantages. Some practical modifications of colorimetric calculations and specifications will be shown. With the proper equipment and special software it is possible to generate Status T density and colorimetry from the same spectrophotometric measurement.

Introduction

Colorimetric methods were not developed by the graphic arts industry. Therefore, it should not be surprising that the special needs of graphic arts color reproduction are not addressed by standard colorimetric methods (Yule, 1965). Most color experts are probably not aware of these special needs. Recognition of the color measurement needs of the graphic arts industry is the first step toward finding a solution.

In graphic arts color reproduction, transparent color ink layers on a white paper are measured. Light passes through the transparent ink layer and any light which is not absorbed by the ink or paper is reflected back through the ink layer to your eye or to the measurement device. Any instrument which is calibrated to a perfect

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white standard will then measure the combined color of the ink and paper. To determine the color of the ink alone, the color of the paper must be subtracted from the combination.

Color pictures reproduced by 4-color printing (or by photography) almost always have a white border or white highlights within the picture which the eye accepts as white. The adaptation occurs instantly and all colors are then seen in relationship to this white. Naturally, there are limitations to the amount of adaptation of the eye but, under the right conditions, any of the papers normally used for color reproduction easily fall within the range of adaptation. Therefore, using the paper as 100 percent white (zero density) in color measurement is to mimic the conditions of human vision. The paper color must always be measured separately to have a complete measurement of any printed color.

In other industrial color measurement applications, such as for paper, paints and fabrics, there is no built-in white reference and color must be measured relative to an external "perfect white."

Since all colors must be reproduced from a subtractive mixture of only 3 inks (plus black), the inks chosen must be highly saturated and very clean. Solid yellows, in particular, can cause problems for conventional colorimetric analysis and specification.

Integrating sphere instruments are commonly used by most industries, but 0/45 degree geometry is needed for measuring samples as seen by the eye. The effect of gloss differences on density is not detected by the integrating sphere instruments when the specular light is included. Specular light can be excluded, but this only works well on high gloss samples (Burns, 1980). Therefore, semi-gloss ink samples cannot be measured accurately with an integrating sphere instrument.

In most industries the size of the sample is no problem. Colorimetric instruments are usually designed for samples of one to two inches in diameter. Solid colors of this size are seldom seen on a press sheet. Most color control patches are about 5 millimeters across and some are even smaller. Some instruments can be made to measure these small areas, even though the basic design is for the larger area.

Solid ink density measurements of strength (ink film thickness) are made using the filter which gives the highest density. In colorimetry, the lightness (darkness) measurement is always based on the "Y" ("L" and "L*" are calculations from "Y") which corresponds to the green eye response. This is the "luminosity" factor which was intended to equal the visual perception of brightness.

Control of solid printing inks by colorimetry using the standard practices would correspond to measuring the density of all colors with a broad band green filter. This may work quite well for most colors, but it does not work at all for a clean, saturated yellow as used in printing. A green filter density measurement of a printed yellow would be about 0.06, which is not enough for good control. Those who measure with paper included would be measuring more paper density than color.

Densitometers are used to control the relative ink film thickness, while colorimetry attempts to measure color as seen by the human eye. It is a known fact that the eye is very poor at judging the ink film thickness of a yellow. It follows that colorimetry must also be very poor at judging yellow strength or ink film thickness. It may be argued that there is no need to control more precisely than the eye can perceive. This would be a good argument if the yellow were to be the final color. In printing, yellow is combined with magenta and cyan to produce red and green. The eye is sensitive to hue changes in red and green caused by changes in yellow strength.

A better measure of yellow strength is the colorimetric "Z" value which corresponds to the blue eye response. In fact, the "Z" is equivalent to measurements made through a good blue separation filter. It has been found that the "Z" can be used directly as a measure of strength without converting to density. Correlation to blue filter density is very good. This is important since densitometers are so widely used in the industry.

The standard instructions for interpretation of the a and b (or a* and b*) diagrams may be confusing to anyone who correctly understands subtractive color theory. The vertical axis is labeled yellowness at the top and blueness at the bottom which is logical, because blue and yellow are complementary colors. The horizontal axis is labeled greenness at the left and redness at the right (Figure 1). Red and green are not complementary colors, but this is primarily a problem of terminology. True red would plot above the horizontal, with cyan on the exact opposite side. True green is above the horizontal with magenta on the exact opposite side.

Figure 1. The L, a, b or L*, a*, b* instructions as normally explained, versus plots of perfect colors on the L, a, b diagram. The color terminology for the "a" axis is not precise.

Color plots of the basic colors and tints on the GATF Hexagon (Preucil, 1960) appear similar to the same plots in the a and b color space (Figure 2). The distance from the center outward indicates saturation in both diagrams. The 50 percent tints, represented by the dotted lines, plot closer to the center than the solids since they are less saturated. The hues of the colorimetric plot are rotated one position counterclockwise compared to the Hexagon.

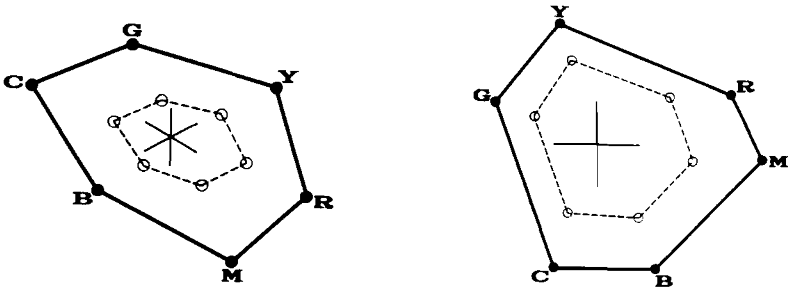

Figure 2. Plots on a GATF Hexagon compared to L, a, b. The straight lines between plots are for illustration only and do not indicate that color mixtures would fall on a straight line.

Those familiar with the GATF Hexagon may apply this knowledge to the interpretation of the a and b plots, rather than relying only on the standard colorimetric instructions. Cyans are often described as being too red by followers of the standard instructions. When a small amount of red is added to a cyan the color plot moves more toward gray than any new hue. The only hue changes possible for a cyan are toward green or blue. The change toward green is an opposite rotation from the change toward blue. The colorimetric instructions would allow one cyan to be described as both bluer and greener than another. A color plot showing a bluer and greener cyan actually indicates a change in saturation.

The a and b calculations alone are often not easy to interpret without plotting them on a diagram. Each number contains both hue and saturation information. The idea of separating hue and saturation into separate numbers is becoming more popular. The hue angle is determined and is used as measure of hue, while the distance from the center (radius) is the measure of saturation or chroma. Hue angle and chroma are simply polar coordinates calculated from the rectangular a and b coordinates. Inexpensive scientific calculators are usually capable of making the conversion.

Unfortunately, plots of increasing concentration do not usually proceed in a straight line from the center of the diagram (Figures 3 and 4). At low saturation levels the curvature is slight and could be ignored. At the saturation levels of printing inks, shown by the outer dotted line on the diagrams, the curvature often becomes so great that a constant hue angle is not an indication of a constant colorant.

The color diagrams shown in Figures 3, 4, 5 and 6 were generated from only 3 actual measurements (yellow, magenta and cyan shown at the outer dotted line). The remainder are calculations of different concentrations and different color mixtures. Actual color changes caused by physical effects such as opacity or ink gloss variation are not shown in this diagram. The lesson to be learned from the calculations is that both hue angle and chroma of printing inks may change at different levels of ink film thickness. Experience is needed to understand the difference between a hue angle change caused by an ink film thickness variation and one caused by an actual shift in the hue of the ink film.

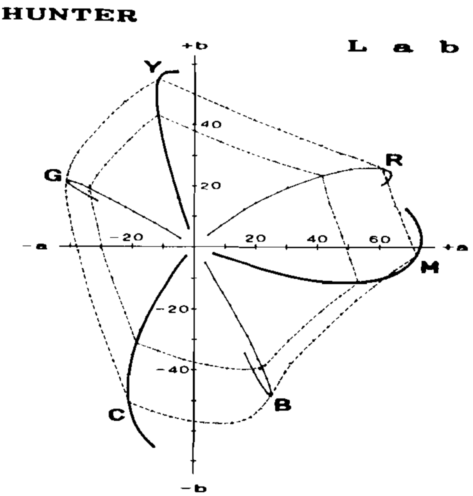

Figure 3. Hunter L, a, b color space. The solid lines represent calculations of identical colorants at differing concentrations

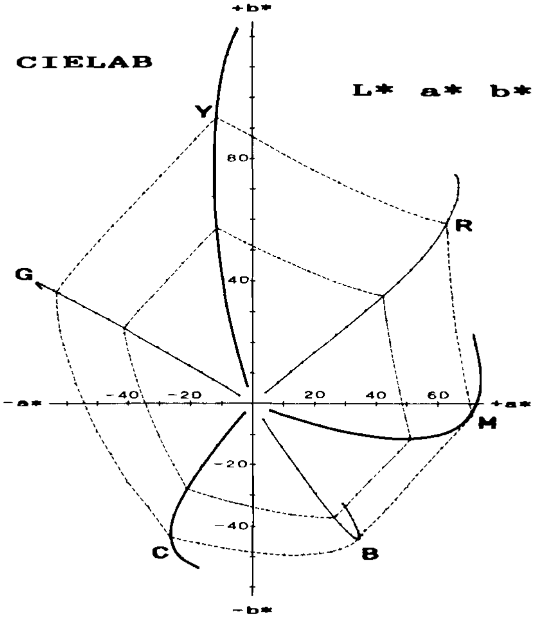

Figure 4. CIELAB L*, a*, b*, color space. Note the extension of the yellow plots.

The lines radiating outward from the center of the diagrams represent calculations of concentrations from 4 to 200 percent of normal ink density for the six basic colors. The outer-dotted lines represent 100 percent concentration while the inner dotted lines represent 48 percent. Note that at normal printing densities a constant hue angle does not always represent a constant colorant. The magenta ink concentration line is nearly 90 degrees from a line drawn to the center of the diagram. In the CIELAB diagram the red curvature is reversed from the curvature in the Hunter diagram.

Proponents of the L, u, v, and L*, u' v' color systems claim that these diagrams have straighter lines (Figure 6). This seems to be generally true, but the lines are still not straight. Anyone speaking of straight line plots of subtractive colors in colorimetry is not discussing the same straight line relationship of the GATF triangle (Preucil, 1960). On the GATF triangle, all subtractive color mixtures fall on a straight line between any two color plots from any position on the diagram. All colorimetric diagrams are additive in nature, which means that additive mixtures of any two lights will usually fall on a straight line. Subtractive mixtures plotted on a colorimetric diagram may appear to be straight over a small distance, but between widely separated colors such as a yellow and a magenta, the line must bend (Hensel, 1984). In industries where closely related colors are being blended, the current colorimetric diagrams are usually adequate for studies of color mixture.

L, u, v color space is not shown because the u' v' diagram is a straight transformation from u, v.

Hardware

Finding suitable equipment for graphic arts colorimetry is possible but the choice of instruments is limited. Anyone seriously considering colorimetry must understand the requirements because the sales representatives of some companies may not be fully aware of graphic arts needs.

Colorimetry may be done with tristimulus colorimeters or with spectrophotometers (Hardy 1936). Colorimetry from spectrophotometric measurements was being done long before there was an instrument known as a colorimeter. The tristimulus colorimeter makes three measurements through three filters which have been matched to human

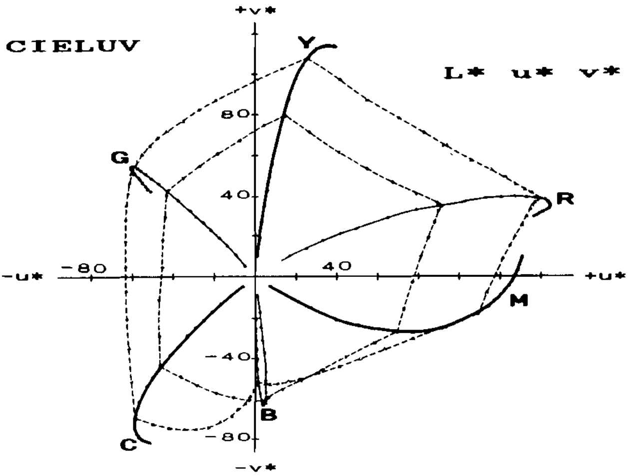

Figure 5. CIELUV L*, u*, v* color space. These plots were made from the same spectral data as used for Figure 3.

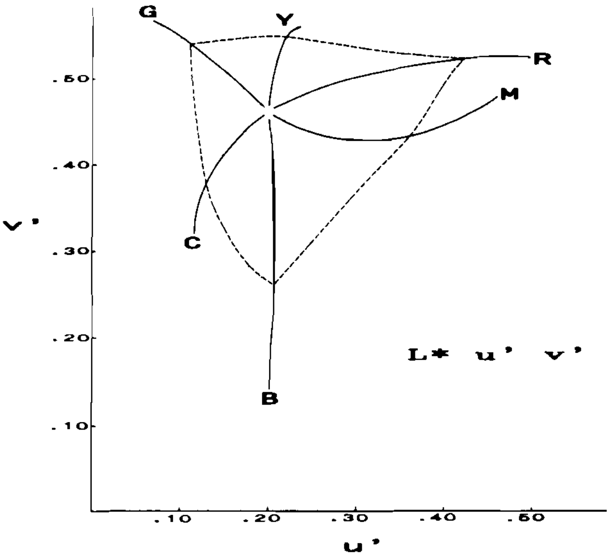

Figure 6. L* u', v' color space. These plots were made from the same spectral data as used for Figure 3. The 48 percent concentration line is not shown.

eye response. While some of these instruments are very good, they are limited in use and are not adaptable to some of the graphic arts needs.

A more useful instrument is the spectrophotometer or spectrocolorimeter. These instruments measure the spectral reflectance over the entire visible range. Eye response is then calculated by a computer, rather than relying on a match from a physical filter. This allows for greater flexibility since any standard observer and illuminant combination may be chosen. D-50, which should match the 5000 degree illumination of the standard viewing booth (ANSI, 1972), may be used. (This does not mean that the light source in a spectrophotometer must match D-50. The illuminant is factored in during the calculation of X, Y, and Z.) The standard illuminants and standard observer are both part of the software, rather than the hardware, of a spectrocolorimeter.

Integrating sphere instruments are not suitable for measuring the color appearance of press sheets (Harold, 1986). Two printed inks which are identical except for the gloss will appear different. An integrating sphere instrument with the specular included will measure them as the same. If the specular excluded option is chosen, it will only be totally effective if the surface gloss is nearly 100 percent (Burns 1980). On a semi-gloss sample some of the specular reflections will be excluded but some will bounce around in the sphere, lowering the maximum density (raising the minimum reflectance) of the measurement.

While it is true that the light source of the instrument need not match D-50, it would be helpful if the ratio of ultraviolet to visible would be the same. Since fluorescent papers and inks are often used for printing, the light source in the instrument should contain a standard, controlled amount of ultraviolet light. Light sources without ultraviolet do not excite the fluorescence of the object being measured and would not match visual judgements in a standard viewing booth. Some currently available instruments have more ultraviolet in their light sources than others. The amount should be standardized and controlled so that measurements of papers would agree between instruments and would conform to visual judgements. Ideally, the ultraviolet content should match the standard D-5000 viewing booth.

Since most color measurement instruments are designed for measuring large areas, it is not always easy to find instruments capable of measuring the 5 millimeter test patches so often used in printing. Those providing for small sample areas often do not provide a means for positioning the sample accurately. Some instruments are designed in a way that the test areas would have to be cut off the press sheet in order to position the sample for measurement.

Software

One of the largest obstacles to widespread use of the systems described here is the software. No commercial software is available at present for doing all of the special graphic arts calculations. Standard software which is supplied with the instruments uses the standard X, Y, Z, L, a, b, or chromaticity coordinates. The D-50 illuminant, needed to match the 5000 degree illumination of the standard viewing booth, may not be contained in some programs because D-55, D-65 and D-75 were the standard CIE illuminants. Therefore, anyone who needs all the calculations discussed here must expect to have some custom programming done.

The software should be written so that all the measurements may be made and stored, as recommended by ASTM and CIE (Alfaya 1984). For each color measurement the spectral data of the ink and paper combination is stored. A separate spectral record of the paper is also stored. When colorimetric values or Status T densities (ANSI, 1984) are needed, they may be calculated with the paper in or out. From the same spectral data the colorimetric values may be calculated for any illuminant or standard observer. Status T density, SPI narrow band or any special density response may also be calculated.

Status T densities calculated in this way represent a nearly absolute densitometer. The values for response at each wavelength, as specified by ANSI, are used in the calculation. No filters are involved. Measurements of the GCA T-Ref show that the system does agree very well with the calibrated values. At least one manufacturer now offers Status T density as a standard program. Others are sure to follow.

Summary

A color measurement system for the graphic arts should include the following:

A. Hardware:
  1. The sample illumination must be 0/45 degree rather than an integrating sphere.
  2. A 4 to 5 millimeter measurement area is needed for measuring test targets from press sheets. Provision for accurate positioning of the probe must be made.
  3. A spectrocolorimeter, rather than a tri-stimulus colorimeter, is needed for greater flexibility in making the necessary calculations.

B. Software:
  1. The program must do colorimetry with the D-50 illuminant.
  2. Status T densities should be calculated from the spectral data.
  3. Provision must be made for using "Z" for control of strength of yellow.
  4. The option for calculating with paper in or paper out must be provided.

Hardware is available to meet the listed requirements. One need which seem unavailable at present is a light source containing a standardized and controllable amount of ultraviolet light. Since most papers and some inks are fluorescent, control of ultraviolet present in the light source is needed to make accurate measurements which will agree with visual judgements and with other instruments.

At the present time no software package will meet all of the listed requirements. Custom programming will probably be necessary for a complete graphic arts program. In addition to the listed software, the user will expect the computer to do the usual color calculations which are now done by many densitometers.

Conclusion

In spite of the difficulty of applying colorimetry to graphic arts uses, one big advantage over densitometer analysis remains. The measured values in colorimetry correlate to eye response. Where communication and long term stability is needed, colorimetry is almost a necessity.

My hope is that, as interest grows, more manufacturers will be encouraged to provide the hardware and software needed by our industry. These improvements cannot occur until there is enough demand to make the ventures profitable.

Until the perfect color systems are devised, it is possible to operate in both densitometer and colorimetric systems from the same measurements. Extra effort is required, but it is often necessary for a complete understanding of color. After operating in both systems I would not give up either the density measurements, needed for the subtractive features and for correlation with the printing industry, or colorimetry, needed for agreement with eye response.

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