MORE THAN CMYK

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Abstract

Many proposals have been made to extend the color gamut that can be printed with process colors cyan, magenta, yellow and the addition of black. For the most part, to illustrate the virtue of an alternate ink set, a display of the gamut is shown on the CIE chromaticity diagram indicating that a larger area is encompassed by the alternate ink set. We have chosen the Munsell color order system as a model to illustrate how certain colorants can be substituted for the conventional CMY and achieve a wider gamut in specific color areas. The substitutes are violet for yellow, orange for cyan, and green for magenta. In certain areas with substitute inks, more chromatic colors can be achieved than those shown in the Munsell Book of Color which is done with pigment mixtures coated on paper.

The flexographic printing process due to the stability and versatility inherent in the system did the printing of the color targets and Munsell pages. The study also examinines several system components to learn how they effect the gamut of color produced.

Current graphic arts technology offers new integrated color management systems, which include measuring hardware and profiling software providing device independent specifications for transforming RGB to KCMY. In order to establish a predictable transfer of ink, a test with a banded anilox roll was used in this study. Printed reproductions were then made of some of the hue pages from the Munsell Book of Color© using profile data and the type of anilox that provides optimum ink delivery.

Introduction

The packaging industry has experienced tremendous growth during the previous and current decade. Package printing graphic design currently includes traditional four color (kcmy) reproductions, color text, and an ever changing complexity of design elements. Flexographic production has grown in its packaging market share providing print on paper, film

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and foil. The impact of color relative to packaging graphics has moved flexographic printers and suppliers to determine the attributes of their print system and optimize color images for reproduction. The era of printing the single potato chip constructed of yellow, magenta and brown ink on a package has passed: now the chip sits in the bowl with other chips flanked by a sandwich crowned with lettuce and tomato.

New technologies and the revitalization of color reproduction have been enabled by digital technology. Screening algorithms, easy access to color measurement tools, and color management workflows are impacting the color reproduction workflow. Colorimetric evaluation of color image attributes has produced an improved recognition of print system performance. The result of technology integration in flexography has been an improvement in productivity and print quality.

Previously noted research of Neugebauer (1937), Murray (1936), and Yule (1967) has presented a view of color reproduction which has evolved from silver based imaging systems to today's pixel by pixel access to color image data. Print systems have also evolved from four color (kcmy) on four unit presses to kcmy plus additional colors as noted in research and recognized patents. Examples include the Mills Davis/HiFi project (1991), Bernasconi (1998), Kueppers (1989), Herbert and DiBernardo (1998), and Lo (1997).

In most cited references additional colors were added to a selected kcmy ink set have been used to enhance an image. Package printing often requires spot or line colors to be matched to a tolerance and further the color must remain consistent through the print run. Separations for printing are color 'simplified' and adjusted for substitute printing colors to meet these packaging objectives. The study described in this paper provides insight concerning the selection of colorants to expand or enhance a color printing gamut. An analysis technique is also introduced which offers a mechanism to easily identify chroma boundaries and contrast the impact of additional or substitute ink colors.

Objectives

The goal of this study was to learn how certain ink colors could be used to augment the color space determined by KCMY. Specifically, it was desired to find a way to use orange or green, or violet inks as substitutes for one of the colors in the KCMY ink set. Several objectives relevant to this goal were developed:

1. Spectral identification of each ink pigment.

2. Printing of a standard target with kcmy and substitutes of complement and adjacent subtractive primaries with violet, orange, and green.
3. Analysis of print results focusing on gamut boundary differences.
4. Determine the efficacy of currently available color management systems (cms) to apply substitute colorants in an ordered and predictable manner.

Certain limitations were self-imposed in this study to limit the scope of the work:

1. Target (IT8.7/3) films were prepared with either complementary or adjacent subtractive KCMY primaries for orange (O), green (G) and violet (V). These provided an analysis of gamut boundaries.
2. All inks were made from a single pigment and identified by their spectral characteristics.
3. Only four color channels were used to keep within the boundaries of certain profiling software.

Methodology

A. Model for Color Gamut

The Munsell color order system was selected to describe the boundaries of the color gamut achieved by specified color ink sets. This system has the advantage of being orderly with the three dimensions of color used by the system being Hue, Value, and Chroma. In the Munsell Book of Color© (1948) there are a number of sample chips that are arranged according to the system and include colors that are both within the KCMY gamut and outside of it. The CIEL*C*h space is an approximate imitation of Munsell space which thus provides a convenient metric for describing the color gamuts achievable by various ink sets.

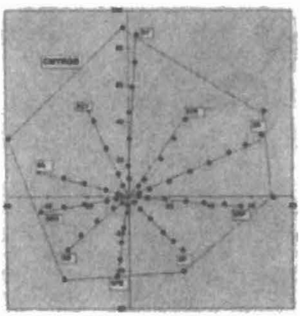

Figure 1: Comparison of Munsell system with KCMY

Figure 1 shows radial lines which are a plot of the Munsell samples for Value 5 plane selected from the Munsell Book of Color©. The irregular polygon in the figure indicates the gamut of colors achievable with a set of CMY inks and their overprints, RGB. This special set of inks is somewhat stronger than the usual commercial products and the outline in a*, b* space suggests that almost all of the Munsell samples could be matched with those inks. However in the course of this study it was learned that other colorants were necessary to augment CMY to achieve higher chroma levels at certain Value levels. See Figure 11, for example.

B. Ink Characterization

In a previous paper (1998) we discussed how various inks could be characterized. We advocate the use of generic Colour Index (1971–1980) names to indicate the pigment in an ink. In addition we recommend an analysis of the strength and shade of the particular inks with spectrophotometric measurement.

Ink specification required selecting colorants that would most likely permit printing the greatest color gamut. The following ink pigments were selected based on color and printability:

Cyan-Pigment Blue 15:3	Orange-Pigment Orange 16
Magenta-Pigment Red 57:1	Green-Pigment Green 7
Yellow-Pigment Yellow 14	Violet-Pigment Violet 23
Black-Pigment Black 7	

Samples were obtained from several manufacturers and were analyzed with a Spectraflow™ instrument to confirm the shade and strength characteristics of each ink.

Figure 2: Spectraflow transmission spectrophotometer

Spectral measurement revealed differences among the supplied ink products. First, these comparisons revealed that all manufacturers were not furnishing the same basic ink pigment for a given color. Spectral measurement quickly told us that one ink supplier delivered a different orange than the one specified. See figure 3.

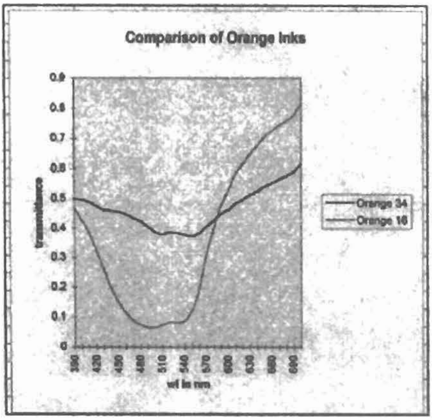

Figure 3: Comparison of Orange inks

Since the spectral measurements gave a quick test of the comparative strength of several inks, all purportedly similar products were examined with this method. Figure 4 shows the strength determinations for Pigment Violet 23 inks.

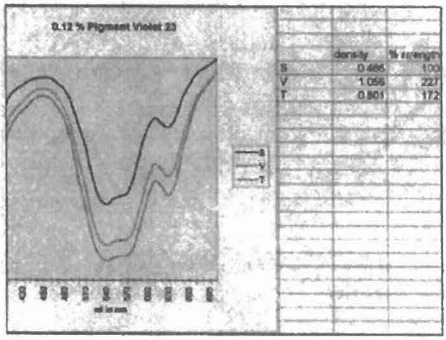

Figure 4: Pigment Violet 23 ink transmission curves

It was desirable to obtain the strongest possible inks for the study since a small volume (2.0 bcm/in^2) anilox roll would be used for printing images of several Munsell pages to learn the limits of color reproduction with various ink sets.

Subtle differences could be detected between ink samples that were supposedly the same. Figure 5 shows that two samples of Yellow 14 were not exactly the same; the sample identified as 'T' in the figure turned out to be a mixture of colorants and resulted in a lower chroma ink as indicated by the lower transmittance between 600 and 700 nanometers.

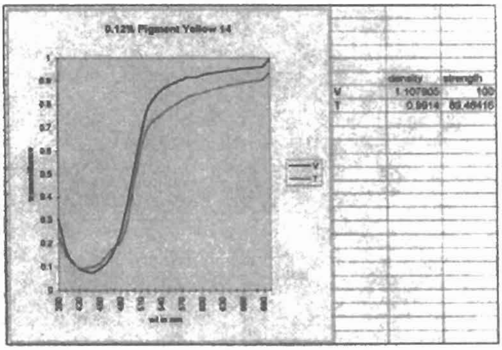

Figure 5: Pigment Yellow 14 ink transmission curves

C Printing Specifications

Flexography was selected as the printing process to reproduce the IT8.7/3 target. Several principles led to flexography being selected: flexography's position in the current packaging markets, process stability, and process simplicity. Production was scheduled on a Comco Captain six station in-line press. Paper was a C1S 10 point substrate. Photopolymer plates were specified at .067 with a relief of .018. Following verification of proper plate exposure a banded anilox roll test was run to identify the optimum anilox roll for soild ink and tint (133 lpi) parameters for the kcmyvog target runs. The banded roll test results revealed best printing conditions using a set of 800 line anilox rolls with a bcm/in^2 of 2.0.

A set of films for the IT8.7/3 target was output consisting of four films. Printing procedures required four plates for the following printing sequences;

1. KCMY
2. KCMV–complementary substituted ink
3. KCGY–complementary substituted ink
4. KOMY–complementary substituted ink
5. KCMO–adjacent substituted ink
6. KCVY–adjacent substituted ink

7. KGMY–adjacent substituted ink

D. Color Target Analysis-measurement, spreadsheet, Rotator

The printed samples were measured with a GretagMacbeth Spectrolino and Spectroscan using D50 as the illuminant and a 2° observer. Spectral data was converted to CIELab for three dimensional plotting in Rotator. Rotator permits plotting from a text file with comparisons from up to four data sets. Data sets were ordered in Microsoft Excel® according to magnitude of the L* values. Separate files were then saved containing CIELab data with L* increments of ten (L* 10-20, L*20-30...). The plots could then be organized by L* values for each printing set. The color data sets were then compared for each color printing set using the traditional KCMY as the basis of gamut comparison.

Color Gamut Plots

Detailed color gamut plots can be obtained with the measured colorimetric data of the IT8.7/3 test targets printed for the various ink sets. The sets are designated by the traditional letters; C for cyan, M for magenta, Y for yellow, K for black, V for violet, O for orange and G for green. There are several four color combinations resulting:

Conventional	KCMY
Complementary	KOMY and KCGY and KCMV
Adjacent	KGMY and KCVY and KCMO

For each of the seven print sets listed above, CIELab data were grouped by CIE L value into three divisions: Light (L*=70 to 80), Medium (L*=50 to 60), and Dark (L*=20 to 30). This then allowed a contour to be drawn around the extreme chroma points for each data set, which indicates the color gamut, achieved with the ink sets. The Light, Medium and Dark compare with Munsell 7, 5, and 3 value planes. Figures (6-8) shows the comparison of several ink sets at the designated value planes.

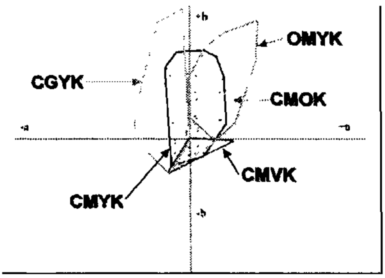

Figure 6: Gamuts by L*/70

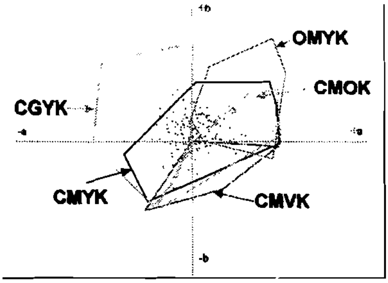

Figure 7: Gamuts by L*/50

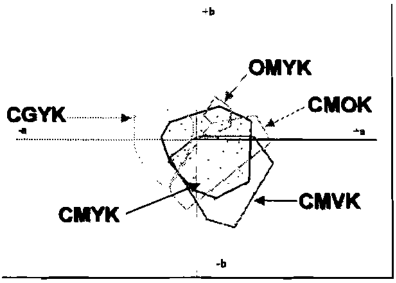

Figure 8: Gamuts by L*/20

A summary plot is shown in Figure 9 which was obtained for all Munsell Value planes which shows the color gamut for the effect of violet 23, orange 16 and green 7 inks when added to CMYK.

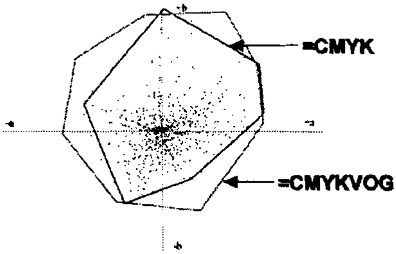

Figure 9: Gamut Additions

In order to illustrate how the gamut plots can be used to compare different printing systems, IT8.7/3 targets were also printed on other printing presses as shown in the following figure:

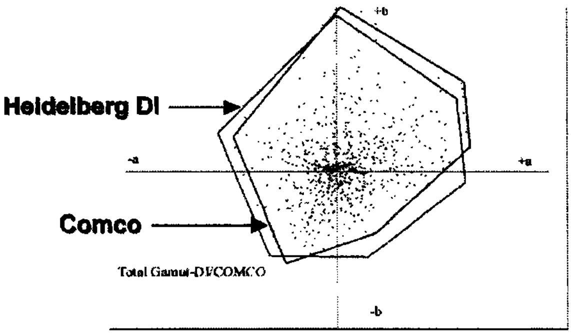

Figure 10: Gamut Benchmark

Color Management

Further comparisons were made by measuring the Munsell Book of Color pages 5P, 5G, and 2.5YR. The pages were measured to obtain CIELab values for each color chip on the pages. The Munsell pages 5P and 2.5 YR were then scanned according to recommended specifications with several Color Management System softwares in order to create 'profiled' color pages from the selected Munsell pages. Films were output, plates made and the pages were printed following the same specifications used earlier in printing the IT8.7/3 targets. Samples of the Munsell pages were selected and comparisons were made using the original Munsell color data as the reference.

With the IT8.7/3 targets that were printed, it was possible to construct profiles for certain ink sets. At the time, data was available for two complementary ink sets, KOMY and KCMV, as well as the conventional KCMY. Two Munsell pages were printed, 2.5 YR and 5P which illustrate how the substitute colorants expand the gamut beyond KCMY. In Figure 11, several arrays of points are shown in an a*b* diagram for the L*=5 plane. The points plotted for the KCMY set indicate that the highest chroma that can be duplicated for 2.5 YR is about /10. Note that the Hue for these samples is slightly shifted toward green (counter clockwise). The results with KCMY for the 5P Munsell page show that no higher than /4 chroma can be duplicated.

When complementary colorants are substituted for C and Y, the most notable effect is that neither set can achieve chromas below about /4. Probably this can be attributed to the fact that the 'normal' 4 channel profiling software requires that a near-neutral sample be present in the data set so that an anchor point be established when a* and b* are 0.

This is a feature that limits the use of such software because the software look up table (LUT) that creates colorimetric a*b* data from ingredient based data requires a near neutral sample in its array. With orange substituted for cyan, the ink that was used could duplicate chroma /14. Two other points on the diagram indicate that with stronger orange inks, higher chromas could be achieved. The cluster of points at low chromas obtained with the violet ink for 5P indicates that the ink was not strong enough; note the single point plotted beyond the Munsell 5P 6/8 indicates that more pigment would produce a higher chroma.

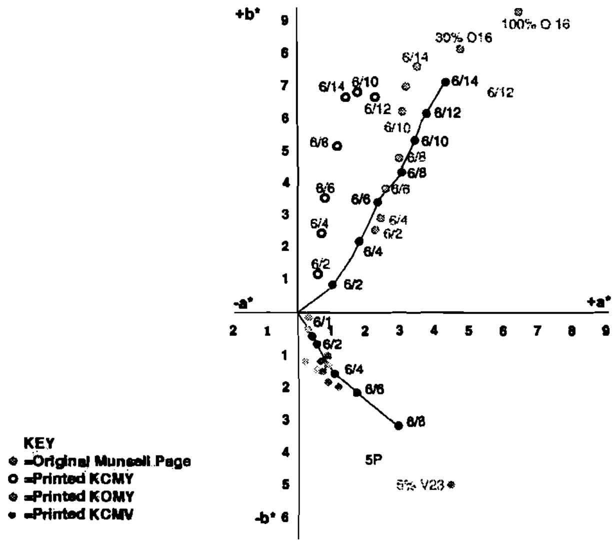

Figure 11: Munsell 5P Value 6, a*, b* plane

Conclusions

What we have learned:

- A refined scope of the problem
- Munsell and L*, a*, b* are viable color ordering models
- How to apply Color Management Systems

Focus for next stage of study:

- Need for flexibility in number of CMS channels
- Improve printing predictability
- Target additions for highlight extensions
- Establish an ordering system for typical color images

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