Color Gamut Analysis of Frequency Modulated Screen Reproduction

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Abstract

A gamut's size and shape may depend on many factors other than the physical properties of its primary colorants. The color gamut created by certain types of frequency modulated (FM) screening technologies appears to be larger than those created by conventional halftone (AM) screens while using the same colorants. Most device gamuts are determined by the physical properties of the substrate and inks. This paper describes and tests gamut-determining factors when physical properties remain unchanged – based on the screens alone.

Color gamut mapping of FM device space is common, and much analysis is available about the factors contributing to an AM/CMYK device-gamut. It is the intent of this paper to provide an analysis of a FM/CMYK device-gamut, compare the gamuts resulting from FM and AM screen performance alone, and to suggest directions of further research.

Introduction

There are two early indicators that the FM/CMYK color-gamut is larger and shaped differently than the AM/CMYK color-gamut.

These indicators are:

1. Anecdotal evidence that the FM color gamut appears to the average observer to be larger than the halftone gamut. Numerous printers and photographers describe the colors produced by FM screens as "full" in color and more accurately representative of the source image.

2. Two papers[1,2] presented during the 1996 IS&T Fourth Color Science Conference describe the FM color gamut as larger than the halftone gamut.

Screening characteristics that result in different AM and FM gamuts is explored. An FM gamut is compared to an AM gamut, Apple's RGB monitor gamut and Pantone's Hexachrome ink-set gamut.

Only one type of FM screen is considered in this paper. FM screens that include phased dot-cluster growth, and organized-dispersed and random-dispersed cellular methods are not considered because the discrete gray-level nature of these screens limit their gamuts. Rather, a FM screen that is the result of analog gray-level conversions is used, because it is with this type of screen that observers notice an increase in coloration.

The color gamuts are described according to CIEL*a*b* color space, Apple Computer, Inc's ColorSync[3] reference and ICC's[4] profile standards.

Discussion

Significant indicators that the FM gamut is of a different size and shape from the halftone device gamut include:

Observations:

FM gray balance of CMY colors is closer to the luminous axis from white point to black point than the AM axis. On press comparison tests of CMY gray balanced patches display an FM balance closer to the white point/black point axis than possible with AM screens.2

The FM color balance of secondary colors is heavily affected by the dominate primary color, moving the balance toward that dominate primary.[2]

Formulas:

FM frequencies are continuous and result in a greater number of secondary colors.

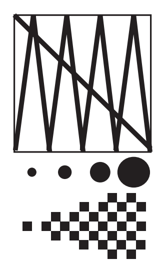

Figure 1. Comparison of discrete and analog dot screens.

An 8-bit PostScript halftone screen consists of 255 discrete dot sizes. Each dot size corresponds to a gray level. An area of a bit map may contain several gray levels.

Let
A = the AM dot level
a = number of gray pixels in an area
b = the gray levels, $0 \leq b \geq 255$

$$A = \frac{b_1 + b_2 \dots b_x}{a} \, trunc$$

An FM screen varies the dot count in an analog manner. The dot count represents an average gray level which may fall between discrete values (normally 8-bit values).

Let

B = the number of dots in an FM area

a = number of gray pixels in an area

b = the gray levels, $0 \leq b \geq 255$

$$c = \frac{\text{screen frequency}}{d}$$

$$d = \frac{b_1 + b_2 \ldots b_x}{a}$$

$B = b \cdot d$ (average dot count)

Since A is always less than B, then the result is a greater number of gray levels in the FM gamut and hence a greater number of secondary colors.

Image definition within saturated areas is increased.

Let

D = the average FM gray level with a modulus

a = number of gray pixels in an area

b = the gray levels, $0 \leq b \geq 255$

$$D = \frac{b_1 + b_2 \ldots b_x}{a}$$

If b = number of gray levels then the modulus results in the following:

$$245 \leq b \geq 255 \text{ and } 0 \leq x \geq 1$$

Let

$$C = \frac{\text{screen frequency}}{d}$$

$(D \cdot C \cdot \text{screen frequency})\text{trunc}$ = number of dots in an AM area

Therefore, FM highlights can contain data within areas lighter than the lightest halftone gray level or darker than the darkest halftone gray level.

AM Modeling Formulas Produce Errors When Modeling FM Spaces

The Yule-Nielsen formula for optical dot-gain estimation depends on the spatial frequency of the screen to calculate the "n" factor[5]. Since an FM screen constantly varies its spatial frequencies, the n factor could be considered as an average of 1.7[6]. The AM screen's "n" values fall into the range 1<= n=>2[7]. The Yule-Nielsen formula will result in values different for an FM area than an AM area of the same density depending on the "n" value of the AM screen. FM screens display a different perimeter-movement curve than AM screens.

FM's dot-touch growth decreases dot-gain to a greater extent than does AM's clustered dot growth. Density measurements collected by the author from various output devices indicate that FM dot perimeter movement follows a 1.8 gamma curve[2]. Forecasts of dot-gain based on the Murray-Davis equation for measuring physical dot-gain would result in an error since the formula assumes a gaussian area growth[8]. Dot-on-dot printing combined with a dot-off-dot pattern is a typical characteristic of an FM screen. Dot-coverage formulas for tristimulus spaces that assume a consistent dot-on-dot or dot-off-dot pattern, such as the Neugebauer[9], cannot accurately predict the coverage of screens that are a random combination of dot-on-dot and dot-off-dot patterns.

In Comparison to Halftone Screens, FM's Dot-Touch Growth Results In Less Perimeter Dot-Gain

The following formula assumes the FM screen consists of square-shaped dots, and the dot's edge length can be derived from a dots per inch specification.

FM screen:

Let

A = total dot perimeters of n FM screen

x = grayscale level in % (e.g. 128 level is .50),
$0 \leq x \geq 255$, $0.00 \leq x \geq 100.00$

n = dots per inch in a vector direction (e.g. 150 dpi)

y = number of primary colors in color space, $y \geq 1$

A = (x • n2)[gamma 1.8]) y

(Note: 1.8 is the gamma that approximates the FM dot-touch growth in this test.)

AM screen:

Let

B = total dot perimeters of a halftone screen

x = % of edge growth. (50% is maximum edge growth)
$0 \leq x \geq 128$, or $0.00 \leq x \geq 50.00$,
$128 \leq x \geq 255$, or $50.00 \leq x \geq 100.00$

n = dots per inch in a vector direction (e.g. 150 lpi)

y = number of primary colors in color space, $y \geq 1$

B = (x • n2) y

then $A \leq B$, FM i.e. dot gain is less than AM dot gain

Optical dot-gain differences between AM and FM screens were not considered in this test. The physical mixing properties of an FM screen were also not considered. It is the author's conjecture that FM's greater dot-on-dot pattern would result in greater physical mixing of primary colors (Brunner trap) yielding different secondary and tertiary colors than AM screens. This is an area of further study.

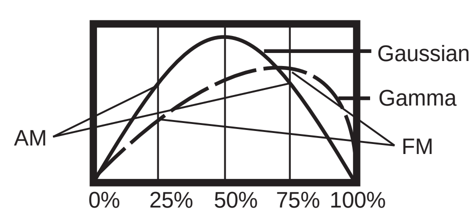

Figure 2. Dot-gain for a colorant consisting of 25% of one primary colorant and 75% of another

FM screen density increases to a larger amount than the equivalent AM screen when the number of dots in the FM screen is greater than the number in the AM screen.[10] The longer total dot perimeters and the tendency for ink to spread greater into voids surrounded by a large amount of colorant result in greater perimeter movement. The dot perimeter movement of an AM pattern is charted as a gaussian curve. The dot-perimeter movement of an FM pattern is charted as a gamma curve across the gradient. It is the gamma nature of the FM screen that results in colors produced by the combination of a colorant with low dot count (quarter tone) and a colorant with a high dot count (three-quarter tone) to move toward the colorant with the higher dot count.

Methodology

Hypothesis:

1. The FM gamut will coincide with the AM gamut at points where the FM screen's density matches the AM screen's density.
2. The difference in location between the FM luminous axis extending from the white point (D50) to the black point and the AM luminous axis must map two different color organizations within the gamuts. The positions of similar colors within the two gamuts will not match.
3. The halftone gamut is usually segmented into 8-bit, or 256 discrete levels through each primary axis. The FM gamut is continuous. The FM gamut will be fuller or more packed with colors.
4. The FM gamut boundary between the primary colorant's saturation points extends further from the white point than the AM gamut's boundary.

Based on the hypothesis, the FM and AM screens would have slightly different gamut models (illustrated in Fig. 3).

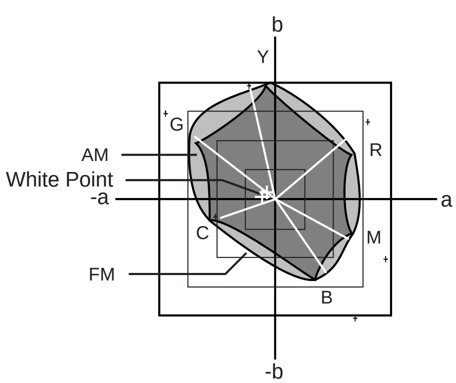

*Figure 3. Forecast of FM and AM color-space differences illustrated in CIEL*a*b*.*

Data Collection:

Film and proofs of test patterns from AM and FM screens are produced and measured.

The patterns used is an IT8-type test pattern in RGB space and a custom test form. RGB space is used to avoid scanner RGB to AM/CMYK and FM/CMYK transformation inconsistencies.

Calculation of Color Gamuts:

The FM/CIEL*a*b* coordinates are obtained from measurements of the IT8 test pattern and verified with measurements of the custom pattern. The RGB to FM/CMYK transformation is obtained from a ColorSync profile provided by RIT Research Corporation. The AM/CIEL*a*b* coordinates are obtained from the same IT8 test pattern using a Photoshop color table. Both AM and FM test patterns consist of identical film densities of each primary color as measured from 15 aim-points along the gradient of a separate gray scale test pattern.

The Pantone Hexachrome 6-colorant system's CIEL*a*b* coordinates are provided by Pantone, Inc. The monitor RGB gamut is provided by Apple, Inc.[12]

Test of Gamut

Film was prepared and a contract proof made. The chroma boundaries, charted in CIEL*a*b* space, were close to gamut forecast. However, the number of colors produced were not counted and the chroma in the luminous axis was not charted.

An AM/CMYK conversion of the IT8-type test pattern was made. Film was prepared and a contact proof made. The chroma boundaries, charted in CIEL*a*b* space, were close to the typical AM gamut.

The saturation points of the AM and FM contract proofs of the primary colors (100% coverage) are similar. The luminous polar axis varies from the AM axis. The FM axis is closer to a perceptual color space axis. (Further research is needed to discover why the FM gray balance is more centrally located in CIEL*a*b* space than the AM which requires more cyan.)

The largest gamuts are those with primary saturated colorants positioned furthest from the origin point in CIEL*a*b* space. The gamuts for Hexachrome colorants and monitor phosphors are larger than the gamuts for either the AM or FM/CMYK colorants. Color spaces composed of more than tristimulus axis expand the gamut by forcing secondary colors, normally composed of the combination of primary colors, outward from the CIEL*a*b* origin. The monitor's gamut is larger due to the phosphor's purer spectral power distribution

The number of colors between the primary axes is greater in the FM gamut than the AM gamut. The discrete nature of the AM gamut limits the number of colors produced while the analog nature of the FM screens produces more colors.

Differences in dot shapes, arrangement, overlap, perimeter movement and alignment all affect the gamut shape. However, these influences on gamut shape are not as significant as the chemical characteristics of colorants or the number of primary colorants. These properties include the colorant's spectral power distribution, transparency and density.

The FM dot pattern may effect the dye colorants by either increasing purity or decreasing dye thickness. Such a change in colorant would account for an increase in gamut at saturation areas. However, dye colorant properties was not measured.

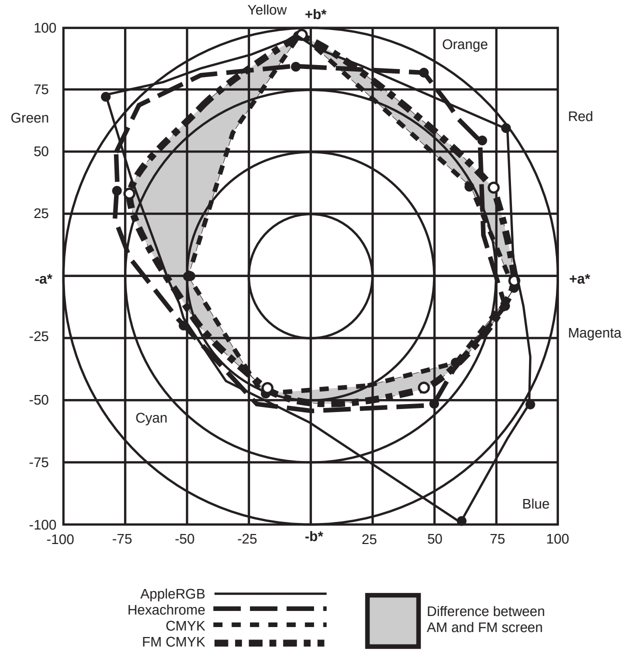

Figure 4. A comparison of color gamuts.

Conclusion:

The observation of an expanded color gamut when the expansion is relatively small indicates that the eye's response to color comparisons is acute. Color accuracy is important when missing colors are psychologically assigned an importance.[13] Such importance is first given to the larger areas of missing colors. The FM gamut increases the reproduction of secondary colors such as purple, green, aqua-blue and red. The Hexachrome gamut is larger still. Where color accuracy is important, Hi-Fi gamuts reproduced by FM screens result in the largest available device space.

In order for a color transformation from one gamut to another to be a close match, i.e. less than 4 to 6 delta E, the gamuts must be device specific. The major determinant of a color device-gamut is the power spectrum purity of the primary colors. However, many characteristics of FM and AM screens differ and result in gamut shape differences. Major differences include the optical and physical mixing of colors, and the gaussian and gamma nature dot-perimeter movement. All contribute to the delineation of the device gamut boundaries and the number of colors within the gamut.

Commercial densitometers using current Murray-Davis and Yule-Nielsen equations for measuring FM densities produce errors. Colorimeters using the Neugebauer equation also result in errors. Such forecasting formulas must be amended to account for variations in gamuts caused by differences in screen performance.

Addendum:

Equipment:
  Imagesetter: Agfa SelectSet 7000
  Film: Fuji HIR film
  Hard proof: Fuji Color-Art Proofing System
  Spectrophotometer: X-Rite 938
    Measured at RIT Research Corporation
  Profile/80 software for preparation of a ColorSync Profile.
FM Specifications:
  FM resolution: 1200 dpi, (21 microns) Icefields' screen
Halftone Specifications:
  150 lpi Harlequin Precision Screening, round-shaped dot

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