3-Dimensional Color Gamut Quantification and Comparison

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Abstract

Color gamut modeling of ink jet systems has proved itself to be an invaluable research tool over the past three decades. It has allowed for the quantitative comparison of the effects of colorants, media, dithering patterns, and many other variables that affect the printers color output. Often the color gamut is displayed as a 2-dimensional projection of the full 3-dimensional volume. It will be shown that critical data is lost in the 2D displays which may lead to incorrect conclusions during ink set comparisons.

Introduction

Standardized quantification of color has been around for 70 years, beginning with the CIE 1931 definitions of Illuminants and Observers.[1] Since that time many transformations have been applied to create 3-dimensional color spaces that are more intuitive or have some other improved feature: some examples CIELAB, CIELUV, and CIELCH. While researchers have used these gamuts to optimize colored systems for just as long,[2] they have proved to be an invaluable tool even more over the past 30 years for digital imaging systems.[3] These standards have enabled the defining of printed color gamuts and their communication with digital printing technologies.

Gamuts are commonly used to compare inks, media, colorants, software algorithms or whole systems. The 3-dimensional gamut of the printer is often reduced to 2-dimensional projections to make comparison easier.[4,5] These 2D projections can be generated quickly and easily by connecting the 6 primaries; Red, Yellow, Green, Cyan, Blue, Magenta. Previous work has presented numerous ways this gamut area can be quantified.[6] Also many software packages are commercially available that use the gamut's full profile data to display 2D chromaticity plots. Gamut profiles are often generated by measuring anywhere from 200 to 2000 color patches depending on the accuracy required.

Full 3-dimensional gamuts are always generated from measuring a large set of printed color patches that were created to define the gamuts profile. From this data various algorithms presented in prior work, allow one to define the surface of the gamut allowing for quantification of the gamut volume.[7,8]

The 2D plots inherently lend themselves to simpler comparisons, but as happens with any data that undergoes compression, information that is deemed non-critical is lost. Thus, the assumption made when comparing gamuts using 2D plots is that the highlights and dark colors are not important.

Comparison Group 1

Gamut comparisons were made of three different ink sets printed using a commercially available six channel (CMYKcm) piezo ink jet printer. Ink Set A was the OEM's pigmented ink set; Ink Set B used all of the same inks as Set A except the pigmented black was replaced with a dye based lightfast black ink; and Ink Set C is a commercially available relatively lightfast dye based ink set.

2D

Primary and secondary color patches (Cyan, Magenta, Yellow, Red, Green, Blue) were printed on the OEM's coated watercolor media. These prints were allowed to dry for 24 hours, and then were measured using a Gretag SpectroScan/SpectroLinea. The a* and b* coordinate values (Illuminant=D50, Observer Angle=2°) were used to determine the area of the 2D CIELAB gamut projection onto the a*b* plane. Projections onto the a*b* plane are located in Fig. 1. Kappele presented the following equation to estimate the area of this a*b* projection, referred to as the G number[6]:

$$G \sim \frac{1}{2}\Sigma_C\{\frac{a^*_{i+1} + a^*_i}{2}(b^*_{i+1} - b^*_i) - \frac{b^*_{i+1} + b^*_i}{2}(a^*_{i+1} - a^*_i)\} \quad (1)$$

Where C is the perimeter of the Gamut Plot, and a^*_i, b^*_i and a^*_{i+1}, b^*_{i+1} are the coordinates of two neighboring primaries-secondary colors. And multiplying the terms of Eq. 1 through allows it to be simplified to:

$$G \sim \frac{1}{2}\Sigma_C\{(a^*_i\, b^*_{i+1}) - (a^*_{i+1}\, b^*_i)\} \quad (2)$$

The G# for the 3 ink sets, calculated w/ Eq. 2, are located in Table 1.

Table 1. 2D and 3D Gamut Values

	2D G#	3D CIELAB Vol.
Ink Set A	11,396	781,685
Ink Set B	11,298	799,025
Ink Set C	10,253	983,875

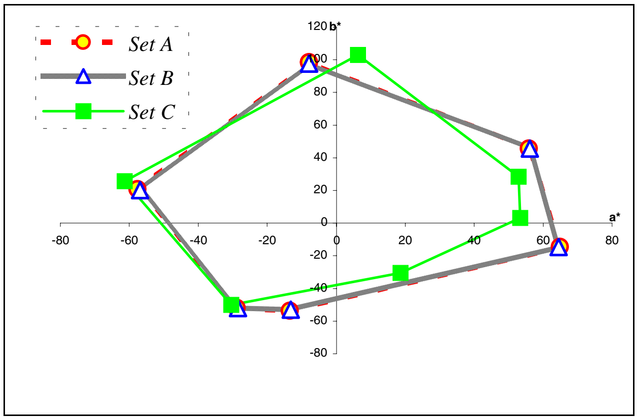

*Figure 1. 2-Dimensional a*b* Plots*

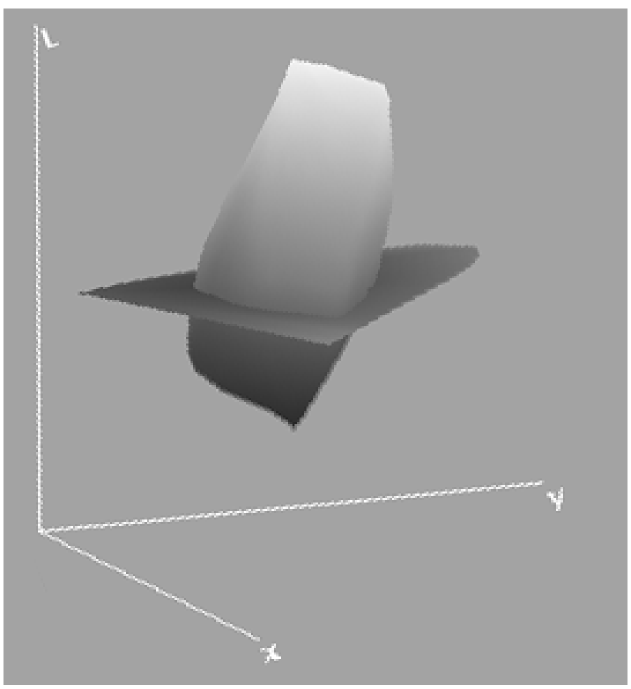

Figure 2. 3-Dimensional Gamut of Ink Set A

Table 2. 2D and 3D Gamut Values

	2D G#	3D CIELAB Vol.
Ink Set D	9,080	591,627
Ink Set E	8,787	611,284
Ink Set F	10.068	880,646

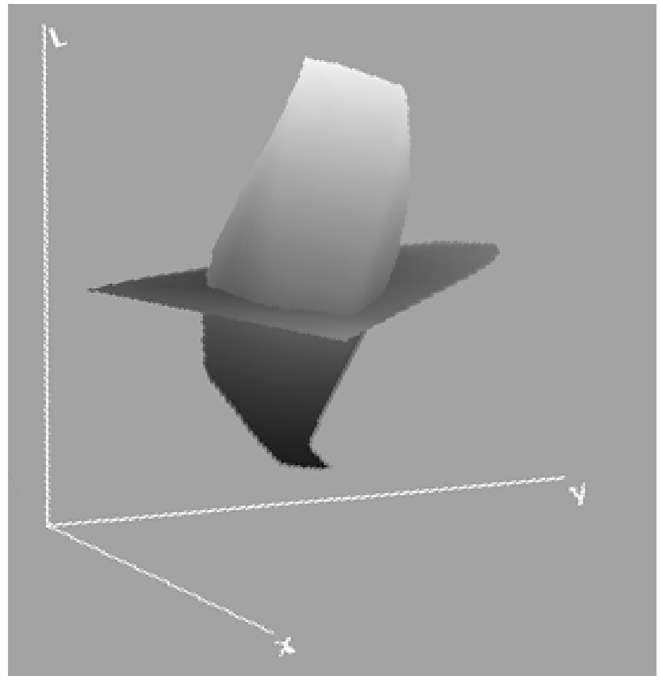

Figure 3. 3-Dimensional Gamut of Ink Set B

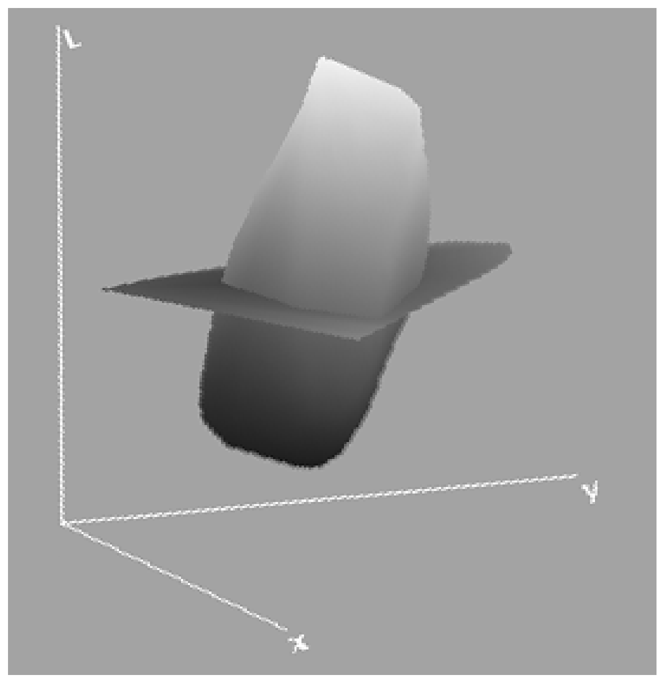

Figure 4. 3-Dimensional Gamut of Ink Set C

3D

Color Profile targets consisting of over 900 patches were printed and measured in a manner identical to that of the 2D color targets. From these values the surface of the gamut in CIELxy space was identified by a proprietary methodology. These mapped gamuts are located in Figures 2, 3, & 4 with the entire CIELAB chromaticity being shown at L*=50.

Then the area of the gamut is converted to CIELAB space, after which the area for all a*b* planes was calculated and summed together to provide the total volume of the printed gamut of each ink set. The results for the 3 ink sets are in Table 1.

Comparison Group 2

The above process was repeated with a different watercolor media on a different ink jet printer that uses four thermal print heads (CMYK). Again 3 ink sets were evaluated: the OEM's pigmented ink set (Set D); Ink Set D where the pigmented black is replaced with a lightfast dye based ink (Set E); and an ink set formulated for this print head using the same dye based lightfast colorants as Ink Set C (Set F).

The 2-dimensional color gamut data projections are in Figure 5, while Figures 6, 7, and 8 show the 3-dimensional gamuts. Note that the perspective was changed from the previous 3D graphs, as this view better conveyed the differences among gamuts. CIELAB area and volume data for these inks is located in Table 2.

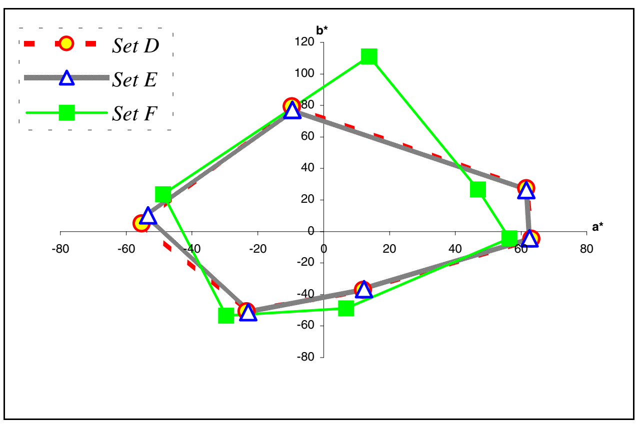

*Figure 5. 2-Dimensional a*b* Plots*

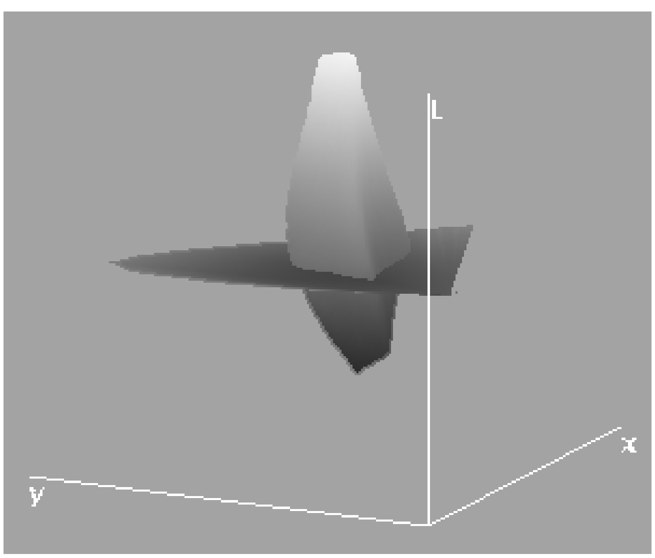

Figure 6. 3-Dimensional Gamut of Ink Set D

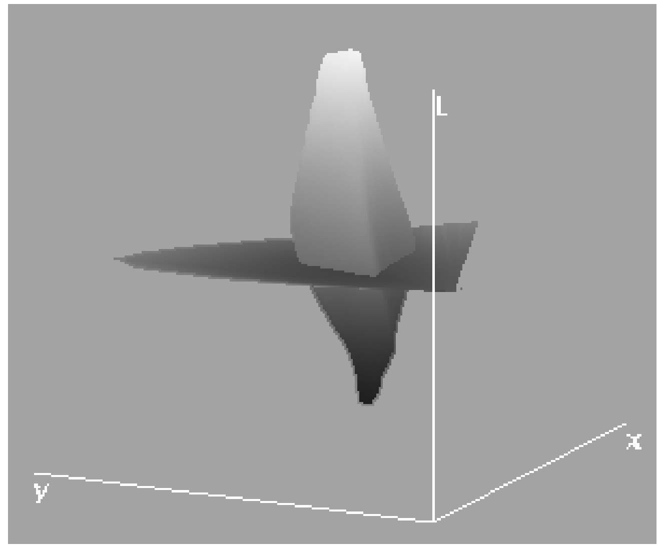

Figure 7. 3-Dimensional Gamut of Ink Set E

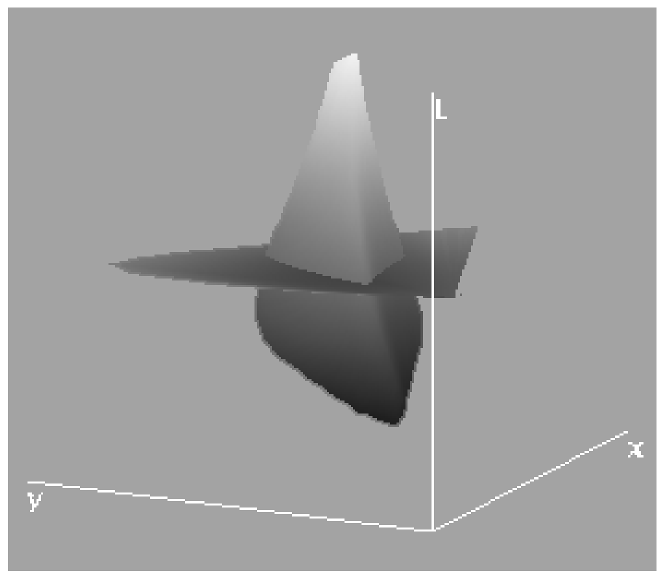

Figure 8. 3-Dimensional Gamut of Ink Set F

Discussion/Conclusion

For the first Group of prints, Figure 1 and Table 1 show Ink Sets A and B to have comparable color spaces as one would expect since the patches from which these plots were generated do not use black ink. From this 2-Dimensional data, Ink Set C appears to have a smaller gamut. However, the 3D gamut volume values in Table 1 show that when all of the data is considered, Set C is found to have a much larger gamut. The complete 3D view provides still further information into all of the trade-offs among the ink sets.

By comparing Figure 2 with 3, one can quickly observe that replacing the pigmented black allowed for darker neutral colors to be printed. The most probable reason for

Set A's low black densities is that much of the pigment is being absorbed into the media, while the black ink in Sets B and C have a significantly higher loading of colorant, allowing them to better saturate the media. Thus, Set B can print images with greater contrast then Set A. And since there are known to exist black dyes that have lightfastness superior to that of the magenta and yellow colored organic pigments typically used,[9] the overall image quality of a system can be improved without reducing its lightfastness.

By adding Figure 4 into the comparison, one can again quickly determine why the 2D data does not correlate with the 3D data. The dye based Ink Set C can create many more shadow colors than either of the other sets with pigments. This is most likely because the aggregated pigments on the print have a much lower degree of transparency than the dyes.

In the second group of prints, the 2D data is not as misleading, but again it does not convey the vast differences in shadow colors among Ink Sets D, E, and F. The same trends observed with Group 1 are also present in Group 2. Thus, both pigmented ink sets can have their contrast improved without any sacrifices by switching to lightfast dye-based black inks. Also, while ever-smaller milling of pigments has enabled them to have more chromatic colors, it ends up hurting the black density in certain cases and this paradox leads to a trade-off in shadow colors.

The greater contrast or detail in shadow colors may not be of great importance for the Point Of Sale signage market, but it is very critical for the Fine Art market. While 2D comparisons are ideal if one is only concerned with the chromatic colors, digital printing's continually improvements are expanding it into more and more markets. With each new application a new set of requirements must be defined and prioritized, and that is when it should be determined if 2D plots will provide all the necessary information.

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Biography

Paul Doll is Director of Research and Development at American Ink Jet Corporation, where he has focused on ink jet ink R&D for over 8 years. He has worked with many of the industry's leading printer manufacturers in developing unique application solutions. He has written and presented several papers on ink jet inks in addition to contributing to a chapter for a recent book on Inkjet Technology and Product Development Strategies.