Color Reproduction Studies in RGB and CMYK Workflows using Inkjet Printer Drivers and RIPs

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Keywords: printer driver, raster image processor (RIP), color conversion, printer linearization, printer characterization

Abstract

This research concerns the evaluation of printed color values when printing to an inkjet printer using a device driver (RGB mode) vs. using RIP software (CMYK mode). The color conversion methodology and algorithms vary from vendor to vendor. The aim of this work is to assess and compare the color gamut produced by different printing methods on the same inkjet printer. An important practical implication of this work is – which printing method gives the user a larger device gamut – device driver (RGB mode) or RIP software (CMYK mode)? To answer this question a number of printing configurations were tested using RGB device drivers (both Macintosh and Windows), and RIP software – ColorBurst, EFI Designer Edition, and PowerRIP X. In order to characterize tested configurations, ICC profiles were created using X-Rite MonacoProfiler. Results presented here show the comparative gamut volume of each printing configuration for an Epson Stylus Pro 4000 printer. It may be expected that as all printing methods ultimately use the same inks, all methods will generate the same device gamut. Outcomes from this work show that the color gamut is different for different printing methods and that the numerical gamut volume is dependent on the vendor implementation. Calibration is also an important part of digital printing and color proofing. Several methods of linearization were tested and compared.

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Introduction

Most printer technologies are based on CMYK inks (or extensions based on "light" versions of C, M and possibly K). Inkjet printers can however be treated as either RGB or CMYK devices. When vendor supplied printer driver software is used, the inkjet printer is considered to be an RGB device. The user sends the device an RGB image and the native printer driver performs the "secret sauce" conversion from RGB to CMYK. This is common in photography and designer-based workflows. In CMYK workflows, such as in prepress and proofing, the user may employ raster image processor (RIP) software and in this instance the device is considered to be a CMYK printer. When a printer is used via its own printer driver software, it is treated as an RGB device and the same printer when using third-party RIP software operates as a CMYK device. The choice of how to treat an output device will depend on workflow and configuration of printing system hardware and software (Sharma, 2004). In this research we describe the relative merits of these two approaches and compare the different color gamuts and linearization behavior achieved when using an Epson Stylus Pro 4000 inkjet printer in RGB and CMYK modes.

RGB vs. CMYK

Photographers may use an inkjet printer in the RGB mode via the freely supplied Macintosh or Windows printer driver. A printer driver, such as that for the Epson 4000 printer, operates in RGB. The user sends the device a contone RGB image and the printer driver internally performs the conversion from RGB to CMYK. If the user were to print a CMYK image it would first be converted to RGB and then sent to the printer as CMYK. This conversion from CMYK to RGB and then back again to CMYK is an unnecessary extra conversion that can lead to unexpected poor results. Used on its own, the printer driver can produce good results as the driver is supplied by the vendor (Epson, HP, etc) who have prior knowledge with regard to their printer behavior. It should be noted, however, that the printer driver embodies a generic conversion that may not be appropriate when using media that are different from what the vendor envisaged.

Using RIP software it is possible to treat an inkjet printer as a CMYK device. In this scenario, a CMYK image is sent to the CMYK printer. The situation is not, however, simply a CMYK to CMYK mapping, as modern inkjet printers have more than 4 color channels.

The Epson Stylus Pro 4000 has 7 ink channels - cyan, light cyan, magenta, light magenta, yellow, light black, and finally matte black or photo black. The newer Epson 4800 has all of the preceding inks and an additional 8th ink called light, light black (LLK). A CMYK image in Photoshop has four channels; however the Epson printers use 7 or 8 channels, thus the CMYK raster data from each pixel in the Photoshop image must be "split" into 7 or 8 channels. The job of a RIP in this instance is to determine how to split pixel information and when for example to switch from cyan to light cyan. Cyan and light cyan (and similarly magenta) are assumed to differ only in saturation or density, and not in hue. A RIP must determine when to use cyan and then make the transition to light cyan and also when and how to blend the different black inks. Along with colorant splitting, the software must also consider printing artifacts, such as banding caused by the print head as it traverses back and forth across the page. To reduce the severity of this pattern microweaving techniques are used, where the print head may be moved, for example, less than a full head width to prevent the banding pattern that was so characteristic of early inkjet prints. In general, the processes implemented by the printer controller include gamut conversion, colorant splitting, screening and optionally microwaving (Aldridge, 2005).

Gamut Volume

The conversion of color data from source to destination space can be done using ICC profiles or by proprietary built-in look up tables in the native printer driver software. Very often the source RGB data is larger than the CMYK gamut and thus rendering intents are used to guide rendering of out-of-gamut colors. To profile a printer in RGB, the RGB printer target containing color patches that sample the input RGB space is used. Printed patches are measured in CIELAB and a printer profile is created that converts colors specified in a device-independent color space to the printer space (Chang, 2002). To create a CMYK printer profile the process is repeated but with a test target designed and arranged in the CMYK coordinate space. The target is printed and measured in CIELAB and an ICC profile is constructed. By measuring these charts it is possible to determine the gamut of a device, or by using an ICC profile we can use software to predict a solid surface gamut plot and hence a gamut volume. An important question addressed in this research is – which printing method gives the user a larger device gamut – native device driver (RGB mode) or RIP software (CMYK mode)? To answer this question a comparison was conducted of the color gamut produced by different printing methods on the same inkjet printer. A number of printing conditions were constructed using RGB device drivers (both Macintosh and Windows) and RIP software –PowerRIP X, EFI Designer Edition and ColorBurst.

Calibration and Characterization

A RIP does not simply control an inkjet printer. A RIP often seeks to create a device with better controlled color environment. To make color more predictable, within the specifications and limits of the devices used, a RIP may employ various device calibration processes prior to characterization. Some RIPs even include special features to facilitate proofing of spot colors (Wu, 2006).

The ink-jet printer calibration process often includes ink limiting. Ink limiting relates to the situation where it is desirable to physically limit the ink used so as to avoid ink pooling. Calibration can also include various forms of linearization. The linearization process is used in traditional prepress to modify the behavior of a device, in order to compensate for factors affecting its response. Because device performance fluctuates over time, periodic calibration is required in order to produce consistent proofs. There are two types: dot gain linearization (linear relationship between the digital reference dot area input for each channel and output value) and LAB linearization (increase the accuracy of lookup tables within the ICC profile, by adjusting the CMYK values so that LAB measurements are distributed more uniformly) (Chagas, 2004; Sharma, 2004).

Calibration processes (linearization) seek to create a printer that is "better behaved". RIP products invest heavily in strategies to linearize a printer. A better behaved printer can produce a much more accurate press to proof match. Another benefit of the linearization process is that it allows users to achieve consistent results across multiple proof devices of the same type in different locations. Generally linearization will slightly reduce the colour gamut of the device. So we see that there is a compromise to be made between larger gamut, but a poorly behaved device vs. a linearized and limited inkjet printer that is better behaved, but may have a slightly smaller gamut volume.

Following all the calibration and linearization processes, the device is characterized where the color response of the device is measured analyzed and stored in the form of a multi-dimensional lookup table in the format of an ICC profile.

PostScript

The PostScript® language (Adobe Systems Inc., 1999) is a page description language devised by Adobe Systems in the 1980s. Its role is to merge and control the text, graphical shapes, and sampled images on printed or displayed pages. In other words, it allows the continuous tone images together with vector images to be used to produce the final printed page. Adobe Systems also created the PostScript RIP technology, which is licensed to different third-party RIP vendors. A RIP can be also understood as a PostScript interpreter, because it interprets the page components (raster and vector data) into the form that the printer understands how to print the file (Rich, 2004). The Postscript color conversion between RGB and CMYK happens in two basic steps (Adobe Systems Inc, 1999; Aschenbrenner, 2002). First is to convert additive primaries red, green and blue into the complement subtractive color primaries cyan, magenta and yellow. In theory, an equivalent of cyan, magenta and yellow colors should generate the equivalent of black color. Unfortunately in practice, CMY inks do not mix perfectly, which can result in shades different from truly black color. Thus, the substitution with true black ink is necessary and this exactly is covered in the second step of color conversion process. The calculation of black component quantity includes black generation (amount of black to be used in reproducing particular color) and undercolor removal (compensation for black addition by reducing cyan, magenta and yellow colors). The correct choice of these parameters depends on output device characteristics.

Each device is configured with default values, which are appropriate for that device, but also can be set manually by operators in dialog boxes.

Experimental

The main objective of this work was to evaluate native printer driver and commercially available RIPs driving an ink-jet printer, more specifically to compare the color gamut produced by different printing methods on the same inkjet printer. An important practical implication of this work is – which printing method gives the user a larger device gamut – the device's native driver (RGB mode) or RIP software (RGB or CMYK mode)?

In order to measure color gamut, an ICC profile was created. Two different modes, depending on the capability of the tested software, were compared: RGB and CMYK mode. Test charts for both modes were generated by Monaco Profiler v4.7.2 for instrument X-Rite DTP70 Spectrophotometer. In order to characterize each configuration, targets were printed without any color corrections or management. The RGB test chart generated by Monaco Profiler consisted of 1728 color patches. For CMYK mode, the ECI 2002 CMYK test target was used. The ECI 2002 target contains a comparable number of patches (1485). ICC profiles were then opened in Monaco GamutWorks v1.1.2 in order to find the gamut volume and see the overall shape of the gamut.

The printer, ink set and paper were used as fixed parameters and such system was driven using different drivers and RIP's. Complete list of the equipment (hardware and software) used in this work is listed below.

Equipment Used:

Hardware:
Ink-Jet Printer: Epson Stylus Pro 4000
Inks: Epson Ultrachrome Inks
Media Type: Epson Premium Semimatte Photo Paper (250)
Spectrophotometer: X-Rite DTP 70

Software:
Monaco Profiler v4.7.2
Monaco GamutWorks v1.1.2
Adobe Photoshop CS v8.0

Tested Printer Drivers and RIPs in RGB mode:
Epson Printer Driver v1.91 (for Mac)
Epson Printer Driver v5.34 (for Windows)
PowerRIP X v7.16 (iProof Systems, Inc.)
EFI Designer Edition v4.2 (Electronics for Imaging, Inc.)

Tested Printer Drivers and RIPs in CMYK mode:
ColorBurst RIP 4.0 (Compatible Systems Engineering, Inc.)
PowerRIP X v7.16 (iProof Systems, Inc.)
EFI Designer Edition v4.2 (Electronics for Imaging, Inc.)

The effects of linearization on the reproducibility characteristics of the tested systems were also studied. This was done in two different ways. Firstly, the tested printer was calibrated using linearization process in CMYK mode through Monaco Profile profiling software, while the printer was driven using ColorBurst RIP 4.0. Secondly, the default linearization file built-in ColorBurst RIP 4.0 was applied when printing to Epson Stylus Pro 4000.

In order to compare linearization results, CMYK LAB channels were extracted from measured test charts. Photoshop comparison of initial and corrected dot area was also done to demonstrate how the profiling software generates new digital file values based on measured linearization target during linearization process.

Results and Discussion

CMYK and RGB represent two different color spaces. Most of the digitally captured files are in the RGB mode and preparing such files must include color spaces of various file elements and also processes in place to appropriately transform or modify data for use with chosen output device. The aim of this work was to assess and compare the color gamut produced by different printing methods on the same inkjet printer. It may be expected that, as all printing methods ultimately use the same printer, inks and also substrate, all methods will generate the same device gamut. However, the underlying methodology and algorithms of color conversion vary from workflow to workflow and vendor to vendor.

The native Epson driver operates in RGB mode and thus takes and wants RGB data. This driver has look-up tables working behind the scenes to convert the RGB to CMYK numbers. This is why when we make a profile with the driver; it has to be an RGB profile. We have a lack of control over the process, due to the fact that their proprietary look-up tables are not accessible. Also, there are more conversions involved in this process: file's RGB to Epson RGB profile to proprietary CMYK table.

The process of color conversion of three different commercially available RIP's was compared to the Epson printer driver by means of gamut volume. Figure 1 shows the comparative gamut volume of each printing configuration for an Epson Stylus Pro 4000 ink-jet printer. Only two of the chosen RIP's supported both RGB and CMYK mode (PowerRIP X and EFI Designer Edition). ColorBurst RIP drives the printer as the CMYK device and it can not process a file with RGB numbers unless ICC profiles are used to convert it to CMYK data for output. And thus when profiling an inkjet printer with ColorBurst, one should always profile it as CMYK.

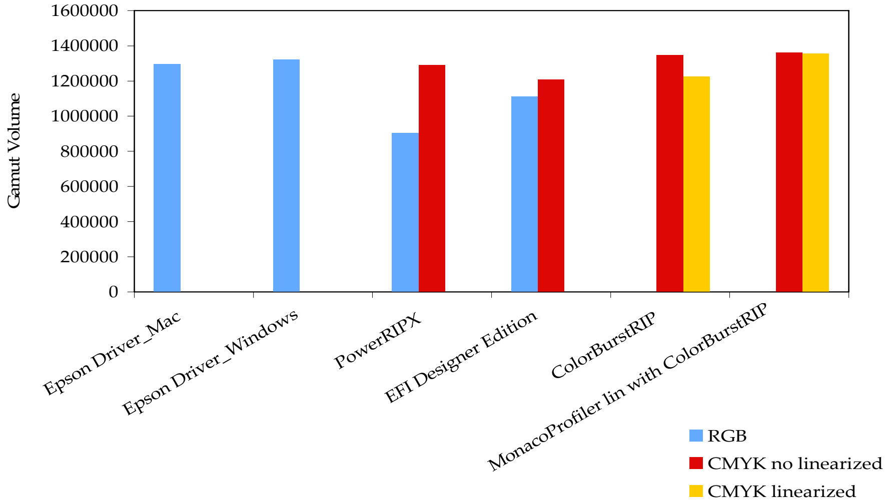

Figure 1: Numerical comparison of gamut volume for each printing configuration for an Epson Stylus Pro 4000 ink-jet printer.

There is no difference between the native printer driver when used with two different platforms (Mac or Windows). Considering RGB mode, there is an evident difference between Epson drivers and RIPs tested in RGB mode, as well as among individual RIPs. Both produce smaller gamut volume when compared to the Epson driver, whilst PowerRIPX produces an even smaller gamut than EFI Designer Edition. Considering CMYK mode, the gamut volume differs for each configuration, ColorBurst RIP being the largest, a slightly smaller gamut with PowerRIPX and EFI Designer Edition, respectively.

Using a RIP with an inkjet printer often involves ink limiting and linearization. Ink limiting relates to the situation where it is desirable to physically limit the ink used so as to avoid ink pooling and poor drying. Each configuration interprets color information in different ways and thus also the nonlinear response of the printer varies for different systems. Linearization seeks to create a printer response that is "better behaved". Both these processes ensure that a printer target can be printed and measured to produce the best colorimetric data from which to construct a characterization transformation or ICC profile.

By looking at gamut volume of linearized ICC profiles created with Monaco Profiler through Color Burst RIP and with Color Burst RIP linearization file (Figure 1), one can see that the Monaco Profiler linearization process was able to maintain the numeric size of the color gamut. On the other hand, when this test is conducted in Color Burst using the built-in linearization file, cutting back in chroma during linearization causes a decrease in gamut volume. There is a compromise to be made between larger gamut and a poorly behaved device vs. a linearized and limited inkjet printer that is better behaved, but may have a slightly smaller gamut volume.

Let's look closer into the printer linearization process. Firstly we studied the printer's response for each configuration without linearization or any color corrections. CMYK Lab channels were extracted from measured test charts for both RGB and CMYK mode. Figures 2 and 3 present chroma vs. dot area relationships for all tested configurations. Evidently, each system implements the color conversion differently and non-linear response of the printer can be seen with all tested configurations. In addition there is a difference between the same RIP but used with different modes.

Linearization of the printer ensures the smooth transition between colors by creating the straight-line relationship between input and output data. It can be performed using a measuring device (spectrophotometer) or visually. However, whereas a measuring device produces exact results, a visual printer linearization is based purely on manual adjustments and should therefore only be performed by experienced users.

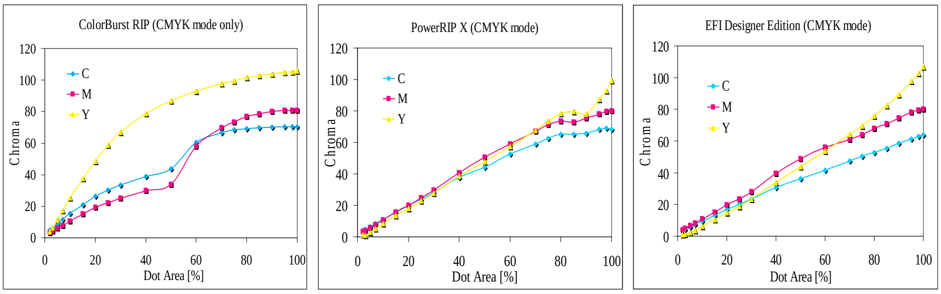

Figure 2: The chroma of CMY vs. Dot area for tested RIP's in **CMYK** mode (Color Burst RIP – left, PowerRIP X – center, EFI Designer Edition – right)

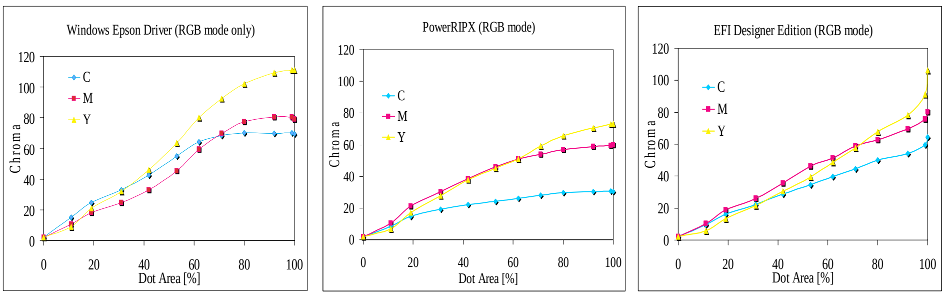

Figure 3: The chroma of CMY vs. Dot area for tested systems in **RGB** mode (Epson Driver – left, PowerRIP X – center, EFI Designer Edition – right)

Let's consider the linearization options in each of the tested RIP's. *EFI Designer Edition* only supports visual printer linearizations. It provides a utility (EFI Ink Assistant) to fine-tune individual ink colors manually by increasing or decreasing the percentage of ink that is used. However, there is also an option to perform an accurate printer linearization using a spectrophotometer by using a specific file created using EFI Windows proofing products (i.e. EFI ColorProof). This product creates a printer linearization files in vcc format, which is supported by EFI Designer Edition. *PowerRIP X* also supports only manual linearization of the printer by defining and adjusting of dot gain curves for each ink. On the other hand, *ColorBurst* offers linearization of the printer based on measured data. In order to linearize, the file with LIN extension must be specified. A linearization file is the curve that corrects for differences in chroma at different percentages. Linearization files for some chosen printer/paper configurations are included in ColorBurst software package. Such files can be also easily created by using SpectralVision software also available as a part of ColorBurst and is compatible with variety of spectrophotometers such, as X-Rite Pulse, DTP41, DTP70 and GretagMacBeth Eye-One and SpectroScan.

X-Rite's Monaco Profiler offers a linearization process by printing and measuring of a preprofiling (linearization) chart in order to define device response. Based on these measurements, the software alters CMYK data and generates a new profiling chart. Linearization with Monaco Profiler is recommended only if the CMYK device or RIP does not have its own linearization option. Additionally, linearization of RGB devices that are not true RGB devices is not recommended, which is the case of inkjet printers that are using CMYK colorants (X-Rite, Inc., 2005).

Based on the above discussed, linearization of Epson Stylus Pro 4000 was tested using two processes. Firstly, we used linearization process in CMYK mode through Monaco Profiler software whilst the printer was driven using ColorBurst RIP 4.0. Figure 4 shows the comparison of tones steps of CMY originally generated by Monaco Profiler and adjusted tone step after measuring of preprofiling chart. Digital dot area was read from Adobe Photoshop CS. Figure 5 clearly shows how the adjustment of CMYK values in profiling chart helped to print uniformly distributed (linearized) LAB values. Figure 6 presents the effect of linearization through ColorBurst RIP on printing conditions. As already shown, gamut volume for linearized profile through ColorBurst is smaller than through Monaco Profiler (Figure 1). It is evident from the slopes of linear lines that the ColorBurst linearization process cuts down the chroma more in comparison with Monaco Profiler, causing a higher decrease in gamut volume and loss of some colors. However, a linear fit is better with ColorBurst in contrast to Monaco Profiler where one can see somewhat saturation and deviation from linear behavior in shades for cyan and magenta (Figure 5). This can be also confirmed by looking at both gamuts of linearized profiles and their cross sections at L = 40 in Monaco GamutWorks (Figure 7).

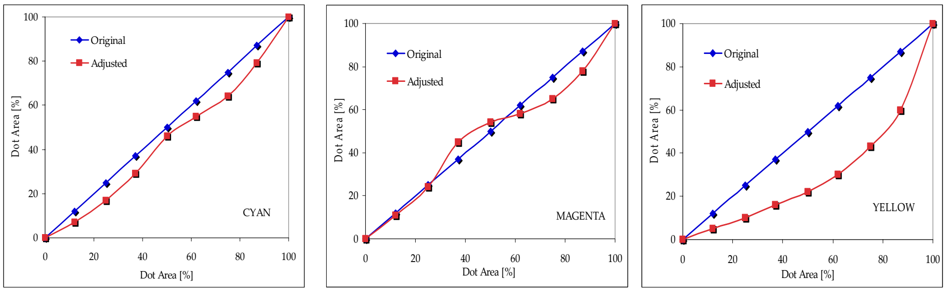

Figure 4: Digital dot area for CMYK chart generated by Monaco Profiler with and without adjustment (linearization).

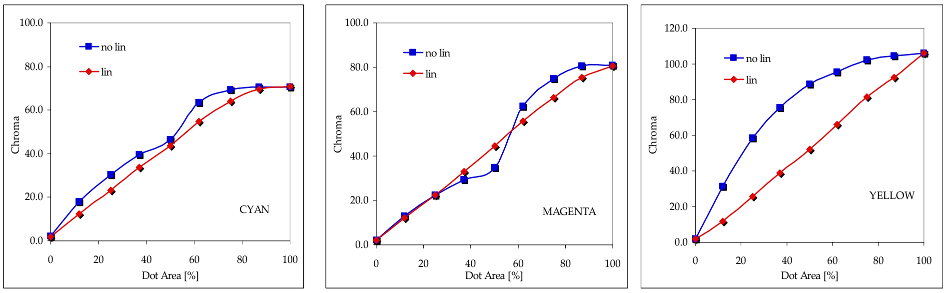

Figure 5: Chroma vs. Dot area for CMYK test charts printed with and without linearization using Monaco Profiler.

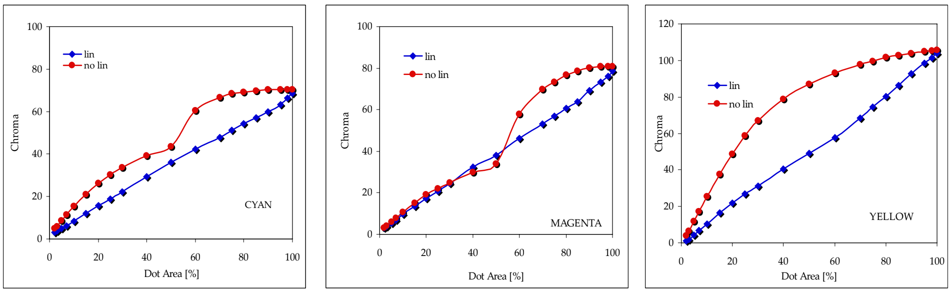

Figure 6: Chroma vs. Dot area for CMYK test charts printed with and without linearization using ColorBurst RIP

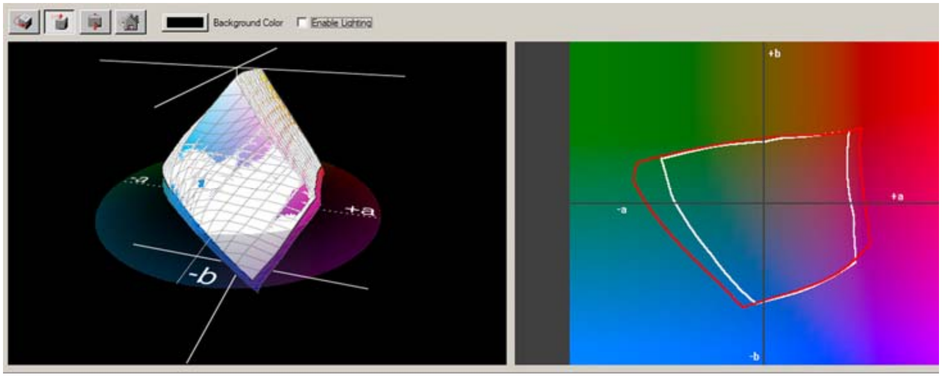

Figure 7: Gamut comparison of linearized profiles (left) and their cross sections (right).Monaco Profiler linearization shown as red (gamut is in true colors) and ColorBurst linearization as white.

Conclusions

The aim of this work was to assess and compare the color gamut produced by different printing methods on the same inkjet printer. Several printing conditions were constructed using RGB device drivers (both Macintosh and Windows), and selected commercially available RIP software – ColorBurst, EFI Designer Edition, and PowerRIP X. An ink-jet printer was characterized by means of ICC profiles created using X-Rite MonacoProfiler. Results presented here showed the comparative gamut volume of each printing configuration in RGB and CMYK mode for an Epson Stylus Pro 4000 printer. The graphs show that the device driver (RGB mode) produces the biggest gamut and that most CMYK RIPs reduce the gamut volume slightly in order to provide better control of the device color behavior.

Additionally, linearization of selected configurations was studied and through reverse-engineering shows the effect of printer linearization and its effect on the quality of the color transformation.

For the record it should be noted that Epson Ultrachrome inks have a gamut generally encompassing all colors that can be produced by web offset while the newer Ultrachrome K3 ink set (Epson 4800/7800/9800) has a gamut that generally exceeds offset. However, some printing conditions, such as the new GRACoL condition for commercial printing can challenge the inkjet in some parts of the color space, so users must ensure that their RIP does not limit the gamut too much. From selected RIPs that were able to print in RGB mode, none of them was able to manage the color gamut as of native printer driver. This might be caused by different RGB color space used by the RIP when dealing with an RGB workflow. On the other hand, the color gamut volume of CMYK profiles was almost the same or even slightly higher than the numeric size of the RGB gamut of the native printer driver. Considering the linearization options of tested RIPs, one should consider what it takes to keep the printer up to its current conditions.

There are many products available on today's market, that it can be confusing to choose the right one that will work the best. The aim of this work was not to evaluate overall option features of selected RIPs. However we finally remark that the RIP selection for particular production will depend on various features offered by the RIP, such as supported computer platform, printers, speed, connectivity, RIP workflow options, color-matching features, etc. A RIP that supports the production imagesetter/platesetter, in addition to the digital proofer, may be preferable in some workflows.

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