Color Management—Current Approaches, Standards and Future Perspectives

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Abstract

Historically, managing color has been a very time-consuming and costly process in the printing and prepress industries. This has led to several years of intense discussions on color management solutions. In response to these discussions, the International Color Consortium (ICC) created a standard which attempts to serve as a cross-platform device profile format to be used to characterize color devices. In this paper, the standard is described along with a discussion of the major limitations of color management today.

Finally, examples of current color management workflows and of ICC color management workflows are provided.

Solutions for Managing Color in the Printing Industry

There have been a number of different approaches to generate reliable color in professional printing in the past. Several attempts have been made to organize these efforts into common industry solutions. A few of these approaches evolved into a general standard in the offset printing environment—the BVD/FOGRA standard[1]—of which wide parts later became an ISO Standard[2].

This standard defines:

- primary colors (as defined in Euroscale[3])
- color of the paper (white point)
- measuring conditions (e.g. black backing behind paper)
- rise of dot gain in the printing process

The US Standard Web Offset Press (SWOP) for the primary colors in offset printing and the comparable Euroscale have recently been unified[4]. In order to periodically check the quality of the state of the color reproduction in press, standardized control strips have been developed that, when measured periodically or on a regular basis, serve as indicators of possible changes of the color. Several press producers[5,6] have developed control methods that translate these measurement data into the control algorithms that in turn set the press ductors that cause the ink flow.[7]

An example of a current prepress color management solution is the system of PVD (Partner vor dem Druck), Germany, as it was sold until the beginning of this year. This software/hardware solution is based on the SGI hardware and operating system. The operator first calibrates the proofer dependent on the characteristics of the individual press for output. The vendor presets his software with a calibration curve, which can be manually changed using measurement results from a—then newly characterized—output device.

The color of the paper is generated as a CMY value which provides to the operator the appropriate value through the following iterative steps. First, the operator prints control strips that, upon measurement, provide input on the color of the paper. Second, the color is varied to some degree and again measured—thus the comparison of the measured results with the data originally intended to be printed stepwise leads to the color of the paper. After adding other factors for gradation or rise of dot gain (which correlate the aim density of the color on the proofer with that of the final output device), this trial and error approach is repeated. Black is regarded as consisting of three colors. Some black noise is added in terms of black dots in order to simulate the paper in the proofer's output.

Having obtained the color characteristics of the paper and that of the primary colors of the proofer separately, the combination of both must be characterized. To keep the machine in constant running condition, software is used that adapts gradation, density and depths (10 values per color in 10% steps between 10% and 100% of density). To keep the system as constant as required the values are measured on a daily basis.

While reliable, the above solutions for the printing and the prepress industries are very time-consuming and complex.

Why OS Based Color Management?

As illustrated above, the traditional printing and prepress color calibration environments can be characterized by periodical configurations of devices such as scanner, computer image processing program, monitor and output devices. Only once, when the system is being set up or for testing purposes, is it necessary to coordinate the selected components with one another. The colors in use are then converted from one device into another, usually without intermediate steps that would allow an open interface by using a neutral coding of the colors such as the CIE Spaces.[8] This interface is required since the market indicates a rise of distributed publishing resulting in a need for reliable color over distances, where customers and producers will not even see each other while having to rely on the produced color quality.

With this background several companies decided in 1993 and 1994 to generate a common approach to color management in order to solve the users problems in achieving reliable and reproducible color throughout the entire reproduction process. The ICCs approach to color management attempts to provide such an open interface so that working with color in heterogeneous systems becomes as reliable and reproducible as possible. Meanwhile this ICC standard is being widely accepted (Appendix 1), so that there is a high probability that this will be accepted by the industry vendors.

The ICC Approach to Color Management

Implicitly the ICC profile standard assumes an architecture that allocates different needed functionalities with respect to where they are supposed to be found in the computer.

ICC Architecture

Within the operating system, a "Color Management Framework", is designated. It takes over the most important color management functions of the operating system (like organization of profiles, giving support to different color spaces, retrieval functions, etc.) From here, the various color management methods are accessed as they are used to convert the image data into the special color spaces of the output devices. Both CIEXYZ are CIELAB are supported as the standard color spaces within the color management framework. Various interchangeable color spaces are offered as part of the standard. Support is given for 7-color printing.

What is in the ICC Profile Specification?

The ICC Profile specification[9] consists of a descriptive part in which Device Profiles, Color Spaces, Profile Connection Spaces, Profile Element Structure, Embedded Profiles and similar components are laid out. This part is followed by Profile and Profile Format Descriptions which contain information, e.g., concerning Device Links, Color Space Conversions. Apart with examples and details on Embedding Device Profiles within Document this closes the document.

Various profile types are specified in the ICC Profile:

- Input Device
- Display Device
- Output Device
- Color Space Conversion
- Device Linking
- Abstract Profile

In accordance with the work sequence, these profile types describe the various areas which are to be characterized, and also give the information on color space transformations and on the linking-up of peripheral devices.

Generating an ICC Profile

One of the first steps in profile building involves measuring the colorimetry of a set of colors from some imaging media or display. If the imaging media or viewing environment differ from the reference, it will be necessary to adapt the measured colorimetry to that appropriate for the profile connection space. These adaptations account for such differences as white point chromaticity and luminance relative to an ideal reflector, viewing surround, viewing illuminant, and flare. Currently, it is the responsibility of the profile building software to do this adaptation.

Currently several vendors use the IT7.8 Standard image containing of some 190 color patches, while other vendors use test images with 4500 patches, in order to compare the digital data with the output and to generate appropriate profiles. Given the statistical noise on the output signal it appears reasonable to measure some 15 to 20 samples before averaging the result. It is still subject to discussions how many patches are needed to characterize a device accurately. A final state of the art in this respect is not yet been achieved. The practical importance which this agreement may have in future is still an open question, as many of the color management systems are evidently not aimed at the printing industry market but at the DTP market. One decisive difficulty here might be the matter of creating favorable priced profiles to characterize the devices.

CMM Approaches

The equipment involved in image processing is distinguished by differing properties for image capture and reproduction. Since the different color spaces involved are not only of considerably different sizes, but also vary in shape, modes for description and adaptation of the colors. Due to these differences in shape, the desired objective of optimum reproduction is not attained by simply making the larger color space smaller. The mathematical operations involved are not linear; thus they distort and diminish the larger of the two spaces until it fits into the smaller space and presents the viewer with an optimum image of the exposure which will follow.

The most simplistic approach is given by a linear transformation of the one color space into the other: As defined in the CIE 1976 Color Space Transformation starting with an XYZ color space and destinating into L*a*b* with

$$\begin{aligned} L &= 116*f(Y/Y_n) - 16 \\ a* &= 500*(f(X/X_n)-f(Y/Y_n)) \\ b* &= 200*(f(Y/Y_n)-f(Z/Z_n)) \end{aligned}$$

In this set

$$f(X/Xn) := \begin{cases} (X/X_n)^{1/3} & \text{for } (X/Xn) >= 0.008856 \\ 7.787*X/Xn + 16/116 & \text{for } (X/Xn) < 0.008856 \end{cases}$$

with $f(Z/Z_n)$ and $f(Y/Y_n)$ corresponding. The index n marks the coordinates of the white reference point.

To give a further example for a way to do the CMM the comparatively simple default mechanism as it is given in the ICC Specification should be mentioned here. This approach uses the input data and the profile of the input device to gain the data in a display. The display under view an example is an RGB device and the input under view is an RGB producing device, too. Amongst others the Input Profile contains several tags that will be used:

Tag Name	General Description
profile Description Tag	Structure containing invariant and localizable versions of the profile name for display
red Colorant Tag	Red colorant XYZ relative tristimulus values
green Colorant Tag	Green colorant XYZ relative tristimulus values

blue Colorant Tag	Blue colorant XYZ relative tristimulus values
red TRC Tag	Red channel tone reproduction curve
green TRC Tag	Green channel tone reproduction curve
blue TRC Tag	Blue channel tone reproduction curve

The forward mathematical model implied by this data to be used for the calculation of the xyz value in the connection space as it is given in the specification is:

L_r = red TRC Tag
L_g = green TRC Tag
L_b = blue TRC Tag

Connection x red Colorant Tag green Colorant Tag blue Colorant Tag L_r

Connection y = red Colorant Tag green Colorant Tag blue Colorant Tag * L_g

Connection z red Colorant Tag green Colorant Tag blue Colorant Tag L_b

This mathematical approach represents a simple linearization followed by a linear mixing model. The three tone reproduction curves linearize the raw values with respect to the luminance (Y) dimension of the CIEXYZ encoding of the profile connection space. The 3×3 matrix converts these linearized values into XYZ values for the CIEXYZ encoding of the profile connection space.

In propriatary CMMs far more complicated models are used[10] to gain results that attempt either to meet referenced originals as close as possible or to meet the way colors in their local environment appear to the eye of an experienced user. Thus two principally differing methods might be distinguished: Match to visual appearance and match to a reference.

The first method under is called "appearance match." This approach to color management tries to take the visual system's ability into account not only to consider the color at a point under view but also the color of the neighboring environment. The second method attempts to match to a reference, meaning match of colorimetric properties in original and reproduces output. Both methods have advantages—while the one is helpful to create the same impression in an output that might be created by looking at the original, it does not lead to measurable data that could be communicated and thus would serve as a measurable security for a remote printing process. It will take some time to see which systems will be accepted for which practical circumstances.

Color Management in a Traditional Workflow

In the workflow through a digital process the image data is "tagged" with the device characterizing data profile. When it comes to output the data, the profiles of the input and output device are used to calculate the colors as they will be represented in the output device. The device characterizing data profiles can be obtained as follows, taking the example of a scanner in its normal settings. Images are scanned in. The colors they contain are distributed as evenly as possible within the color space. The digitally stored reference data (for example those from a disk supplied along with the photograph) are read into the computer for comparison purposes. This comparison between the data supplied by the scanner and the previous data for the same image provides good information on the reproduction properties of the scanner. After a reading-in process such as this, the computer "knows", the color into which the scanner will turn the particular digital data.

The changes in workflow required to do the color management using the ICC profiles are minor. Given a setup of devices consisting of scanners, monitors, different output devices and software could involve a practical example that would work as follows:

1. Characterization of scanners using a profile making tool
2. Characterization of monitors using a profile making tool
3. Characterization of output devices using a profile making tool
4. Scanning and reading of the images into a tool like Photoshop
5. Match of scan to color space of monitor or match of scan to color space of monitor including other output devices
6. Reading of both images into an other tool i.e.Quark or Pagemaker if required a further match to color space of monitor including other output devices
7. Output

As it can be seen in this scenario the linking of profiles, meaning the ability of the color management mathematics to match the color spaces of different possible devices for the output is essential to the usability of this approach. This becomes more difficult if different output devices, ranging from slide printers to computer-to-press processes, are included especially when the output device is not known at the time the reproduction is done.

Communicating the color further on into the output device leads to some requirements for the database handed over with the file to be e.g. printed:

The system should be able to integrate or to access data that permit:

- Presetting of ink ductors and rollers, where possible
- Controling of scaling devices for the mixture of inks
- Calculation of ink recipies of data in file
- Accesing and creation of statistical information on ink consumption
- Support operator
- Request optimal set of primaries

Evaluating first results on how the ICC approach to color management meets the customers requirements draws the attention to the lack of the required tools in the field. A user of profiles would obviously need either generic or customized profiles for the systems in the local environment under view.

The color management sold today are equipped with generic profiles for most of the devices on the market. A user wanting to produce an own profile would have an easy task if characterizing a scanner since this device could measure the incoming data and the profile generating tool would compare the input data with measured data describing what the scanner should have detected. The comparision delivers the characteristics of the device. Well defined tools like the IT8 targets are available for that purpose.

Output devices like monitors or printers are somewhat more difficult to characterize since measurement devices are required. Several vendors did come up with tools for monitor characterization. Characterizing the printer turns out to be somewhat more of a problem. The user under view has to be aware of the noise underlying the signal of the printer and, to avoid problems occuring because of the noise to measure a sufficient amount of prints to average over the noise. At the time this paper is written there are no adequate tools available that would permit end users to generate their own printer profiles. Thus the experiences we can rely upon here, do describe cases in which profiles were generated by the CMM vendors.

Examples

The first experiences were gained while preparing the demos of the work of the ICC for conferences (FOGRA conference on advances in computer publishing February 1995, Seybold Conference, Boston, March 1995). The devices used in the example of the Seybold demo were two scanners on the input side six computers using four different operating systems and color management tools coming from four different vendors. It turned out that the results produced therewith proved that using different devices and tools led to comparable results.

Due to the lack of tools there are not too many experiences with color management out of the lab environment. A good example of the few cases is the following problem: A large magazine producer usually uses rotogravure to print his products. For one occasion he wanted to personalize the cover of the magazine which was not possible with the devices available. The decision was made that the cover should be printed using a webfed offset printing device available in an other factory. Earlier at FOGRA under standardized conditions the sheet fed offset device had been characterized. The web fed offset printing had then been set to the standardized conditions described in and the profile gained in for a different press could be used. The profile of the proofing device (IRIS) and the offset profile had been linked thereafter to enable the operator to simulate the final result. It turned out that the results gained with that approach met the requirements of the advertiser and the publisher.

So far the first results are positive for the ICC approach. However, the color of the paper did cause some problems in other case of usage since if the color of the paper changes, a new profile is needed. Especially in newspaper print first results indicate (14) that the eye is very sensitive even to small changes of the white point of the paper and thus even minor changes in the paper require new profiles which might not be handy at all times.

Limitations of Color Management?

Limitations of color management occur due to several circumstances, but two factors seem to be most important—one is the average time needed to evaluate colorimetric differences in images and the other is the statistical deviation an output device undergoes when working under usual conditions.

The accuracy of the calculations involved have been subject to frequent discussions. The upper limit to the accuracy appears to be given by the number of patches the system would use to calculate the profile for use throughout the process. Users we approached accept a profile calculation process (such as in Linocolor or in the learning process of the neural net used by the ELTEX system) lasting for hours after the actual measurement of color patches (which is about an hour in itself). They assumed that if the approach serves the business this loss of time would be justified.

A loss of time in the retouching process appears not to be accepted, though, because if the adaptation of the color data to a new color space uses the front end for too long a time the lack of productivity becomes obvious. In the long run, only algorithms working “on the fly” seem to be accepted. The system used in the first compatibility demos met this requirement though some do still no have all the functionality needed for a professional use built in.

On the other hand every output device undergoes some statistical deviations in the accuracy they are able to reproduce an original even in typical use. In the offset and in the rotogravure processes these values range around 2 – 4 delta E[11,6] while desktop printers and proofers undergo larger errors.[12,10]

Without supporting the idea of an undefined “good enough quality,” an advertiser should recognize that statistical material evaluated by the advertising industry indicate that advertising images are used by an user for less than an average of five seconds while, of course the person deciding whether to accept the work of the prepress shop spends more time in the effort to evaluate the quality of the work. Other data[13] indicate that there is a correlation between the time an image is looked at and the accuracy needed to derive a correct impression of the colors used:

Comparison between reproduced copy and original by an inexperienced user:

Delta E and approximate time to realize that difference from original

Delta E	Approximate time to realize that difference from original
15	5 Seconds
10	10 Seconds
5	15 Seconds

The actual measured differences in CIELAB delta Ethat are needed to distinguish a colorimetric difference is still an active area of research and debate. Some research indicates that a delta E of 1.0 is enough for the human visual system to differentiate between different colors in case of looking at color patches such as in the IT8 targets while others indicate that in an image taken out of a real world environment values of less than 2.5 delta E are not visible to the usual user.

This leads to the impression that an accuracy of the color management method smaller than the ability of the output devices ability can’t be reasonably required. Still, this is desired in order not to add possible errors due to the different processes involved in the whole color reproduction workflow.

Summary

The need for color management results from the possibility of producing variable system configurations combining differing individual components produced by different manufacturers. The user is not restricted to his own specific facility but can choose between different products. Open system concepts at the prepress stage make it necessary to find new ways of dealing with color on the computer. This ICC profile standard provides a viable solution to this problem while requiring few changes to the current workflow.

*The specification reported in this paper has been created by several engineers of the founding members of the ICC. It's a pleasure to express thanks to Michael Stokes who intensively worked over preliminary versions of this paper and made me aware of errors and needs for further explanation.

Appendix 1

The founding members of the ICC were Adobe Systems Inc., Agfa-Gevaert N.V., APPLE Computers Inc., FOGRA (honorary), Microsoft Corporation, Eastman Kodak Company, Sun Microsystems, Silicon Graphics Inc., and Taligent Inc.

A number of computer and software manufacturers have given this problem their attention. To mention just some of the current vendors the following list should give some overview while quite some vendors more:

* Adobe	PostScript Level-2
* Agfa	FotoFlow
* Apple	ColorSync
* Candela	Candela CMS
* Canon	
* Color Architect	MatchMaker
* Color Blind	
* Daystar	ColorMatch/ColorMatchPro (KCMS)
* EfI	EFI-Color
* Kodak	KCMS (Precision/Colorsense)
* LightSource	OFOTO
* Linotype-Hell	LinoColor 3
* Microsoft	KCMS Kodak
* Pantone	POCE (LightSource)
* Photone	Photone-CMS
* Prepress Techn.	SpectraCal
* Silicon Graphics	Kodak CMM
* Strom	ColorProof (Candela)
* Sun	KCMS Kodak
* Tektronix	Tekcolor

In other industries using color, such as the textile industry, vendors restricting themselves to the individual market, are also active.

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