DEVICE INDEPENDENT COLOR REPRODUCTION

Jan De Clippeleer*

Abstract

In open professional desktop publishing systems, color management systems are needed to guarantee consistent color. Open systems rely on flexible and standardized ways of interfacing and communicating color information. This paper will focus on the technical and colorimetric implications of some upcoming and growing de facto standards for color information in color management systems, image file formats, page description languages and operating systems. Quantitative evaluations will be done using the IT8.7 standards.

Introduction : The Problem of Color Reproduction in Open Systems.

The professional users in the graphic arts industry today have adopted desktop systems for the production of black and white publications. They have walked the learning curve to the end and feel in control of the process. These users are now looking into color and are challenging vendors to provide professional tools to help them walk the curve of desktop color publishing.

The vendors are working very hard to provide the basic building blocks which enable the desktop user to take on color jobs. Personal computers have more power, more memory and can drive 24 bit color displays. Typesetters are replaced by accurate color capable imagesetters and black and white scanners are replaced by precise color scanners. EtherTalk, large capacity disks and network servers help to overcome the communication and storage problems posed by working with color images. Systems seem to become open, 'plug and play', at least on the hardware - i.e. physical interconnection - side.

What is than the problem ? The problems the users are facing have to do with the way vendors implement devices and systems. In many cases, the user is the system integrator ! How to make a color reproduction with all those pieces of equipment, without being a color expert ? How to be sure that an original will be printed as the user expects it will be. The problem is how to control the differences in color behaviour of devices and media (scanners, color separations, proofs, color printers etc.) in an easy way that the user can understand. Vendors have to provide tools which make it possible for the user to be in control of the reproduction process.

*Agfa-Gevaert N.V., Mortsel, Belgium

The Trial and Error Process

Due to the interaction of displaying or printing technology and color dyes, monitors, offset presses, laser printers and film recorders have recognizable color differences. The range of colors these devices can print are not matching. The printable range of colors is usually referred to as the color gamut. A scanned image is a collection of RGB values, which are heavily determined by the RGB filters, the scanner designer has selected. There is no guarantee that these RGB values, displayed on a monitor will produce the same visual impression as the original. So, the user has to modify the scanned RGB values to match the original, with respect to the color appearance.
Software developers have invented curves, tables and lots of controls to help the user during this matching process. This is a trial and error process because the user has no idea of the color gamut of the devices and the matching is not a trivial operation. Today many users are going through this discouraging process. They are experimenting with curves and lookup tables, without really knowing what is happening, until the result is acceptable.

Color Management Systems

It is clear that there is a need for an integrated way in dealing with colors in color reproduction systems.
The challenges of every color reproduction system therefore are :

- dealing with many devices that handle color differently,
- dealing with the particularities of the human perceptional system,
- converting from many colorspaces into other.

All the software components, standards, tools and methodologies which are necessary for doing this, are typically referred to as a 'Color Management System'.
The goal of Color Management is to bring more consistent and predictable color and to make color device independent and more portable.

Some vendors designed one or another 'core' 'color engine', containing the basic functionality of color reproduction :

1. Tools for **'local' calibration** of devices in order to bring them back to the original 'default' state of the vendor.
   Typically densitometric linearization or normalization tools.

2. Tools for analyzing, **characterizing colorimetrically** color devices, resulting in color characterization information.

3. **Managing color characterization information** throughout the imaging chain.
   Typically referred to as ColorTags or profiles.

4. **Preparing a color matching session.**
   Based on color characterization information.
   Typically also solving the problem of color gamut mapping.
   Typically referred to as ColorLinks or color transforms.

5. **Using the color transforms** in an application environment,
   while capturing the image, while processing or
   while outputting the image.

6. **Reporting** additional information on the color matching process
   (e.g. which colors are unprintable,...)

The value of a Color Management System is proportional to the degree to which these components are integrated, but sill modular and open and not aimed at specific devices or vendors.

Since steps 2) to 6) are fully colorimetric, in many cases intensive three dimensional computations have to be done.

In terms of 'packaging' this (or part of this) colorimetric technology, it can be found back in the imaging model or 'framework'
of software applications on workstations,
of image file formats,
of graphic software libraries embedded in the operating system,
of page description languages in raster image processors for output devices.

The best known standard color frameworks in open desktop publishing systems are TIFF (Tagged Image File Format), PostScript® (Adobe's page description language), ColorSync® (Apple's Operating System framework to plugin Color Management Systems).

We will not go into the details of each and every data structure or software subroutine. We will focus on the conceptual color architecture and its implications on color accuracy.

The Importance of a Good Color Model in the Imaging System

Inspired by the well-known paradigm of "device-independency", most of the imaging models are trying to establish a relationship between device dependent signals in the imaging device and the device independent (often CIE-based) colorimetric counterpart of it. A relationship between the colorimetric reality (CIE XYZ, CIE Lab,...) of a certain original or reproduction on one side, and the device dependent signal (RGB, CMYK,...) on the other side.

This relationship is the basis for a translation process which helps in the process of color matching.

Some popular imaging models in their early versions often claim to solve the complete color transformation problem by focusing on primary chromaticities. I.e. reducing the above relationship to a simple linearization. These models are inspired by the imaging model of a CRT monitor display which, indeed, in many cases reacts pretty linear.
In many cases the designers have chosen the linear simplification as the default of the system. Luckily, the architecture of most system allows for non-default extensions which can be driven by more sophisticated models.

Let's summarize briefly some color building blocks of some of those systems :

- the basic color information in many popular applications and in the mandatory default fields of profiles of ColorSync 1.0 is counting on linearity and focusing on chromaticity information per colorant. Also, a 1-dimensional preprocessing (gamma-function, normalization, linearization) is applied to the signal.

- In the 'input' part of PostScript Level2, a suite of two sets of 1-dimensional transferfunctions and two 3x3-matrices is used as color model. In the 'output' part a multidimensional lookup table is added to the model for better translating the non-trivial interaction between the signals, allowing higher-order interactions than the basic 3x3 linear matrix multiplications.

- Like some other vendors (EFI, KEPS), AGFA has added in the FotoFlow product family, more functionality and better color reproduction with more sophisticated color transforms in own applications but also in the framework of existing de facto standards (ColorSync operating system extension, PhotoShop application plugin modules,...) by using optional and additional data and algorithms.

What are the advantages and disadvantages of linear models versus more sophisticated ones ? Which color errors are introduced ?
As a simple example, we will confront the linear model with polynomial functions of higher order. Although one can proof that there are much better color algorithms possible than polynoms, we use polynoms as a straightforward and didactical extension to the linear model.

Evaluation of Color Models based on Polynomials.

We will analyze the color quality of certain color models, when they are applied to real life examples of film scanners or offset printing processes.
In contrast with the linear model we simply extend the analysis to higher order polynomials.
Three dimensional polynomials of the first, second or third degree will be used to convert device dependent signals into the corresponding device independent CIE color values. With conventional regression techniques, the coefficients of the polynomials are determined to minimize the least mean square error between measured and predicted colors.

For the scanner model evaluation, the chosen set of test data are the reference colors of the IT8.7/1 target
For the printer model evaluation, the colors of the CMY combinations in the printed IT8.7/3 target are used.

Scanner Model

A set of three three dimensional polynomials is used to predict X, Y and Z from R, G and B :

$$X = PolX(R,G,B)$$
$$Y = PolY(R,G,B)$$
$$Z = PolZ(R,G,B)$$

3 terms :

$$X = a_1R + a_2G + a_3B$$
$$Y = b_1R + b_2G + b_3B$$
$$Z = c_1R + c_1G + c_3B$$

8 terms :

$$X = a_1R + a_2G + a_3B + a_4RG + a_5GB + a_6RB + a_7RGB + a_8$$
$$Y = b_1R + b_2G + b_3B + b_4RG + b_5GB + b_6RB + b_7RGB + b_8$$
$$Z = c_1R + c_1G + c_3B + c_4RG + c_5GB + c_6RB + c_7RGB + c_8$$

The models with 27 and 64 terms are extensions of the examples shown above, containing second and third powers in the products of the sums.

Fig 1.a to Fig 1.d show the distribution of the delta E color error between the measured and the predicted color value.
Fig 1.e shows the accumulated distribution of the same color errors.

It is clear that by gradually increasing the order of the polynomial model a better prediction of the colors can be achieved. Or : by forcing forcing the the imaging model to be linear, a substantial color error from the model is introduced on top of all other errors like : measurement errors, noise, quantization errors,...

Offset Printing Model

A set of three three dimensional polynomials is used to predict X, Y and Z from C, M and Y:

$$X = PolX(C,M,Y)$$
$$Y = PolY(C,M,Y)$$
$$Z = PolZ(C,M,Y)$$

The same evaluations with 3, 8, 27 and 64 terms are done.

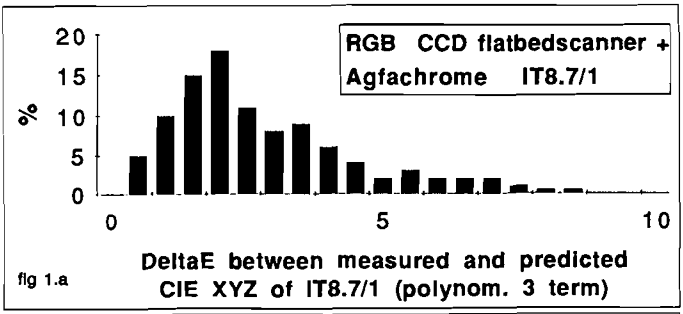

fig 1.a

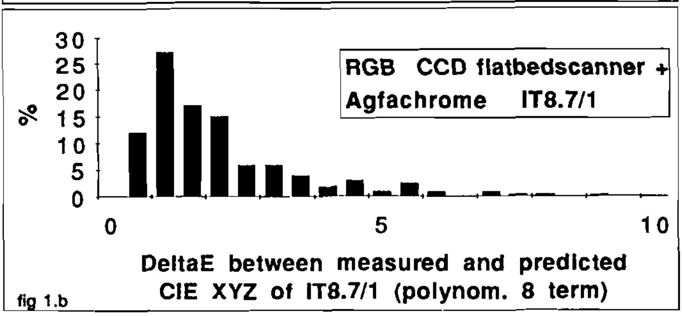

fig 1.b

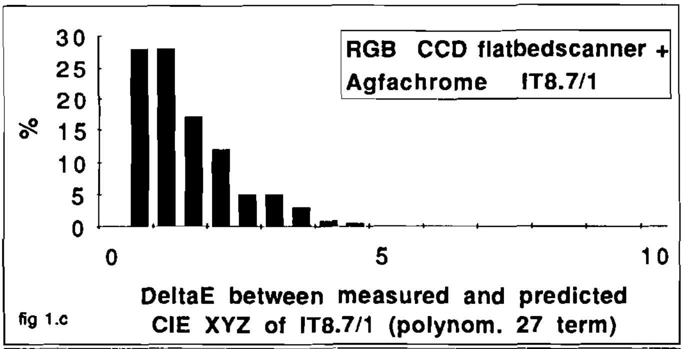

fig 1.c

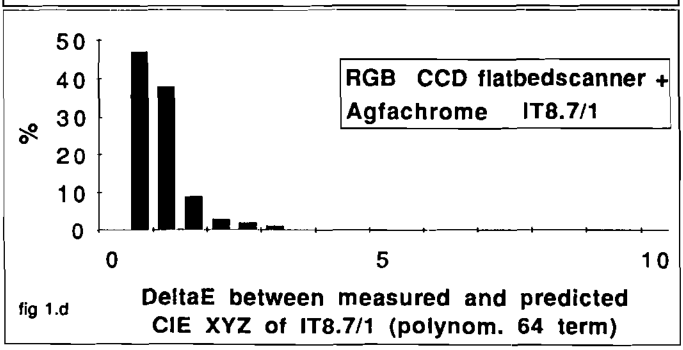

fig 1.d

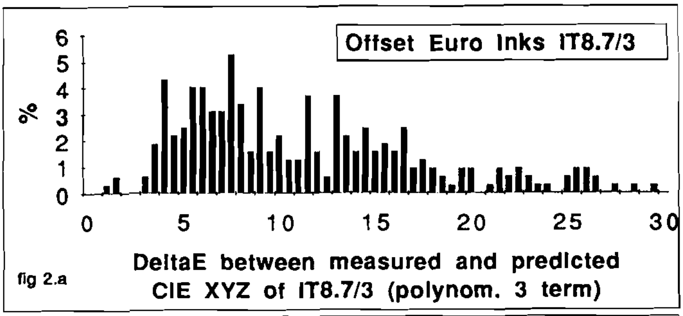

fig 2.a

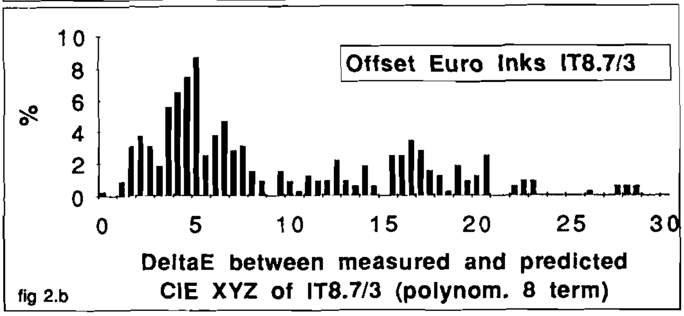

fig 2.b

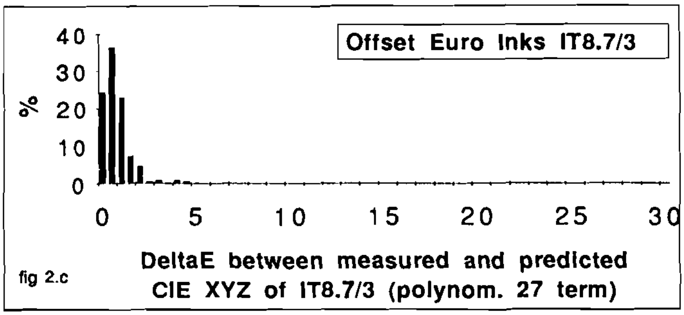

fig 2.c

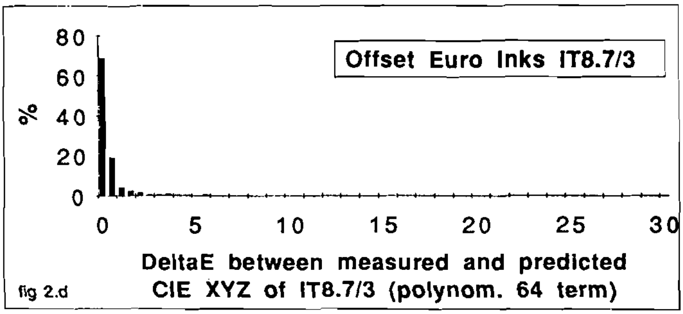

fig 2.d

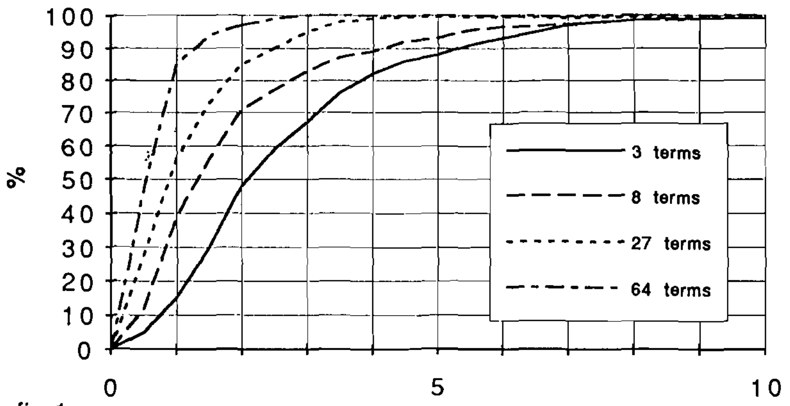

fig 1.e

Accumulated distribution of deltaE between measured and predicted color values of IT8.7/1

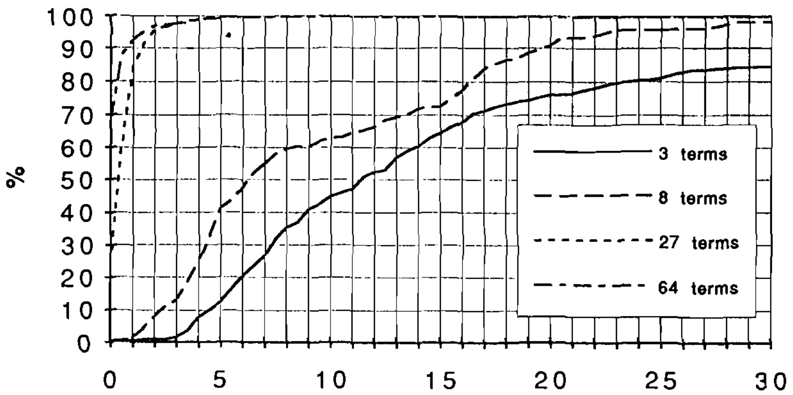

fig 2.e

Accumulated distribution of deltaE between measured and predicted color values of IT8.7/3

As shown in the figures fig 2.a to fig 2.e an even more dramatic behaviour is visible. Due to some more pronounced non-linearities in the subtractive imaging technology of offset printing, the simplification of the linear prediction model introduces unacceptable model errors leading to very high deltaE values.
The added value of a more sophisticated printer model is obvious.
This explains the more complex models for output devices in imaging models like e.g. PostScript.

CONCLUSION

In this experiment it was shown what the impact on color quality can be of the imaging model that is chosen in the data structures and architectures of color reproduction systems.
As an example polynomial approximations were chosen.
Although polynomial approximations have many other disadvantages in practical circumstances, it was shown that, specifically for modelling output devices, color errors with higher order polynoms are already much lower than with linear models.

In general, it was indicated that a color management system should contain enough technology to fit into all kinds of frameworks (simple or sophisticated) that are required by the application. Different quality levels can be achieved depending on the effort that is done in the different applications.
In this perspective, AGFA developed the FotoFlow Color Management System, based on the IT8 standards, fitting into different application contexts, ranging from high to low end. One and same high-end color technology was designed as a superset of many needs in different application contexts, ranging from prepress to photofinishing to medical applications.