The Role of Color Management in Digital Prepress Workflow

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Color management allows to control and standardizes the process of color reproduction from the original input (a scan or digital capture) to the eventual output (a printed page or website) via the intermediate devices (designers monitors and proof prints). Color management is intended to ensure a good matching of colors in a modern digital workflow. Such process becomes possible due to a spectral analysis of printed colors. Color device profiles are the components required to transmit color information within the color management system. ICC profiles are created on the basis of spectrophotometric measurements. Such profiles describe the deviations in device-independent color space of the specific device and allows the system to manipulate them.
On the other hand, for the same image we often have different reproduction requirements depending on the reproduction process itself and the stage in the workflow at which the reproduction is made. For example, an image on a computer display may be required to accurately match the color of the original image, or to be a pleasing (idealized) reproduction of that image, or to be a color match to a printed reproduction of the original (soft-proofing), which, in turn, may be a color accurate or a pleasing copy of the original.
The investigation focuses on development of optimal digital workflow of color data depending on the aim of the color reproduction process and kinds of printed production. For these reason we have made a formal description of color reproduction process. All important decisions about a kind of reproduction required at each stage of a workflow has to be made by a designer and taken into account during color management system setup. Therefore, the development of an predictable workflow of color data is a very difficult and important task.

1. Introduction

One of the important directions of development of the image processing and printing industry is the integration of prepress, press and postpress technologies under management information systems. For this process it is necessary to pass from isolated solutions of the management of the information transformation and quality control of printed production to a systematic review of the total technological and technical problems. Thus, all stages of technological process are combined into the information flow that provides joint work of equipment of the printing company. This flow is managed by an automated management information system (MIS).

MIS is a system that provides information required to manage organizations effectively. This modular software and hardware system consists of multiple components, some of which are shown in Figure 1. Data transfer in the system based on open standards: JDF or PPF - job definition format or print production format; ICC – allows to match a color when moved between applications and operating systems, from the point of creation to the final print.

The structure (figure 1) defines the interaction of major functional subsystems of MIS between them. In this case accumulation, storage, transmission and conversion of the color information are forming a separate class of problems of the technological process. The important part of management information system is color management system. It is required for graphical information processing by input, display and output color reproduction devices and implementing data processing algorithms and for other aspects.

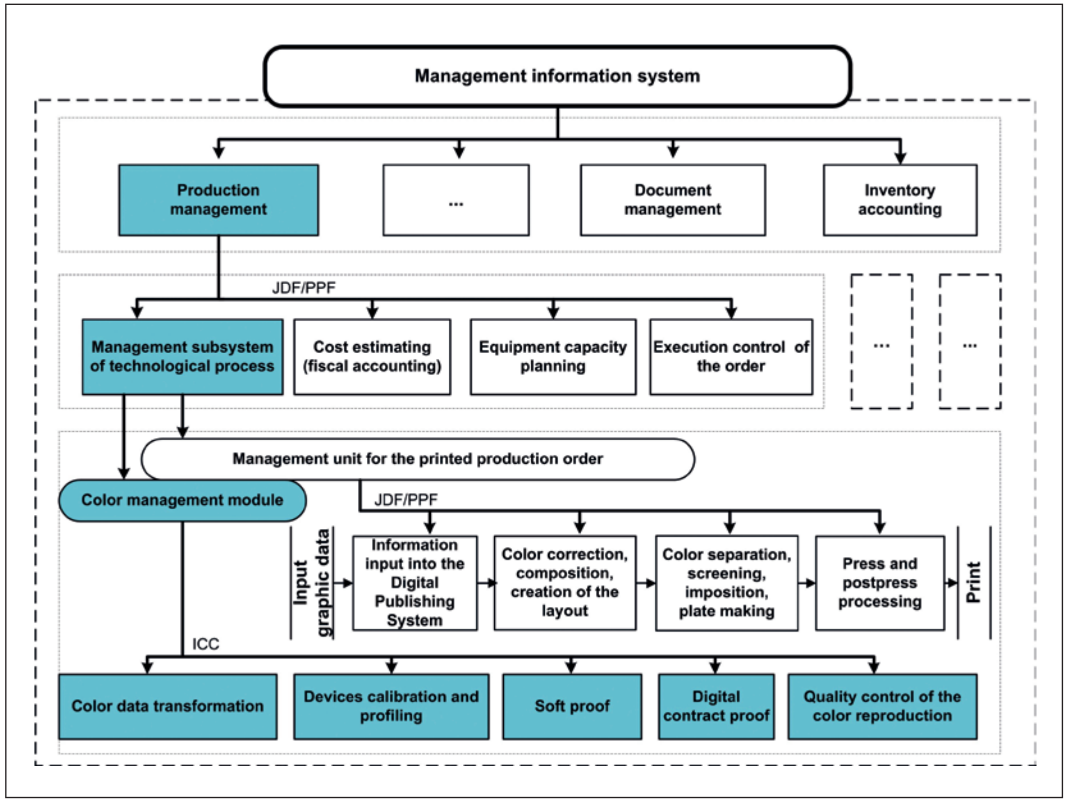

Figure 1: Structure of the MIS

2. Digital workflow of the color graphic information

The process of color reproduction in printing consists of the following stages [1]:

- analytical stage is represented by reading the color information of each element of the original image and its translation in the form of three color components corresponding to the transmitted (reflected) light streams in three zones of the visible spectrum - red, green and blue (RGB);
- at the stage of gradation and color correction the image converts into a suitable form for the next printing process. This stage includes the transformation of color information from the source to the target color space (from RGB to CMYK or another model through the device-independent color space Lab) mapping the original color space into a target color space with a color gradation conversion, providing psychological or colorimetric accuracy;
- transition stage or the plate-making stage, in which the selected components are recorded (color-separated images). The recording on the photographic materials, on magnetic media, on forming materials (plates) or on the forming cylinders (in gravure printing, digital printing, DI-technology). It also includes necessary technological operations: screening, correction of nonlinearity of the recorder, etc.;
- printing process of the image on a physical medium (paper, plastic, etc.) and receiving a final print. It includes overlaying and combination of color-separated images with appropriate colors of the synthesis and formation of the images on a print. This stage is defined as a synthesis of color images on the print or printing.

Mathematically, color transformation is presented on the ICC-based color management scheme. Digital image is transformed into hard-copy image as follows: device dependent signals (RGB) are transformed into device-independent color space (XYZ) through the source profile; then XYZ are transformed to cone signals (LMS); and then, the simple von Kries adaptation model is used to get the corresponding cone signals for the output image using viewing condition parameters. Therefore, we have three stages: direct transformation, gamut mapping and inverse transformation. For these transformations we need profiles of input, display and output devices.

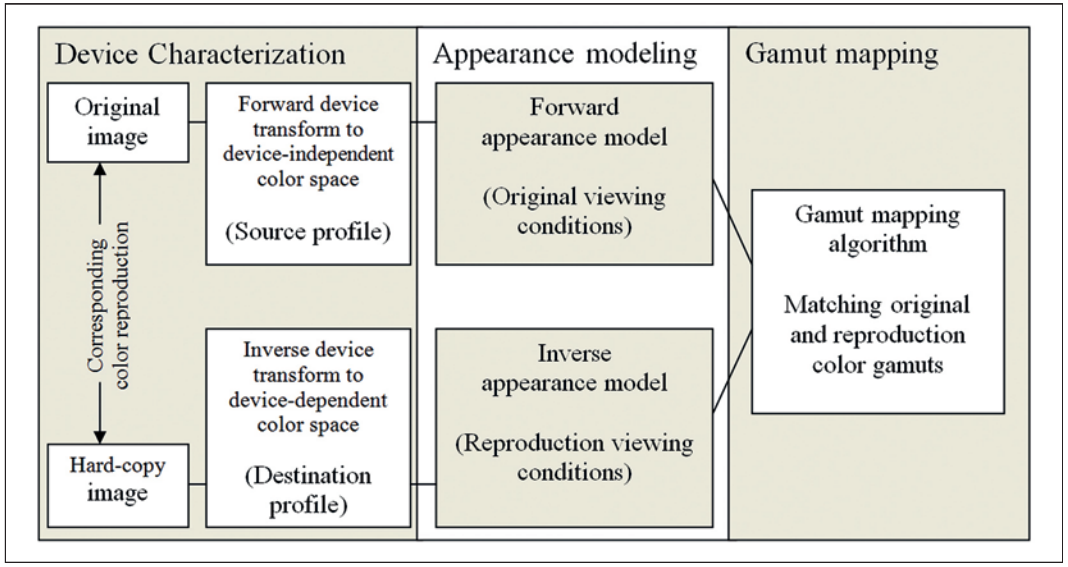

Figure 2: The scheme of digital color data transformation

In workflows where multiple devices might be used, and particularly where the devices may not be known at the time of image capture or generation, proprietary systems are often impractical. It was primarily for such workflows that the specification for ICC profiles was established. Its goal is to provide a mechanism for defining the color of image data in a way that makes it possible to exchange images between systems, while retaining any color requirements imposed on the image [2].

3. Structure of the Color Management System (CMS)

The main objective of color management system is to provide matching between the gamuts of various colorimetric systems (scanner, monitor, printer) used in color reproduction process. The main goals of color management system in prepress process are following:

- colors of the original image should resemble the color of the print, or, if correction of these colors is made, printed colors should be as close as possible to the colors of the image on monitor;
- colors of the original image must be accurately reproduced by the monitor;
- colors of the soft proof or digital proof should be precisely reproduced during the printing process.

To be successful, color management must consider the characteristics of input and output devices in determining the appropriate color data conversions for these devices [2].

The principle of operation of the color management system is as follows: using the color data obtained from the device profiles, the software module converts the color of the input device's color space to device-independent color space and then simulates the same color in the color space of the target device with the purpose of goal of the reproduction. The number of such transformations is undefined [3].

Color management helps to achieve the same appearance on all devices, which are capable of delivering the needed color intensities.

Parts of this technology are implemented in the operating system (OS), helper libraries, the application, and devices. ICC-compatible color management system are cross-platform ones. The ICC industry consortium has defined an open standard for a Color Matching Module (CMM) at the OS level, and color profiles for the devices and for working spaces (color spaces the user works in) as well as devicelink-profiles representing a complete color transformation from source to target.

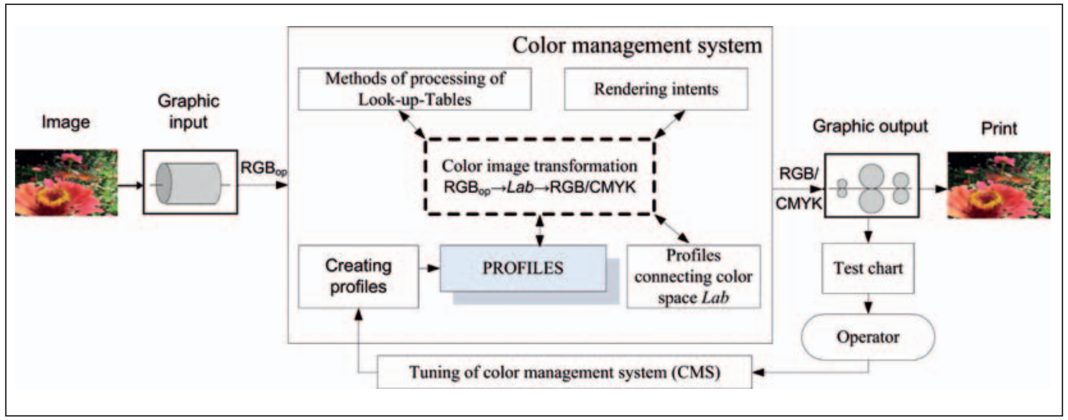

Figure 3: Structure of the color management system

Therefore, by means of color management system, namely, the profiles of color reproduction devises we can control and correct the reproduction process in order to achieve the required accuracy of color reproduction print.

4. Calibration and profiling process

For the correct operation of the color management system it is necessary to consistently calibrate the equipment, normalize the technological process of manufacturing printed products, as well as characterize all the color reproduction devices, namely, create a profile of each device involved to manufacture of printed products.

Calibration is the process of setting up color device for a given state, for example, in case of monitors to a certain white point and gamma correction. Calibration ensures that color reproduction system from day to day and from machine to machine will produce stable results. Calibration can be performed in the absence of information about the relationship between hardware signals and colorimetric coordinates, while the colorimetric characterization of the device requires the obligatory presence of such information [4].

For the effective implementation of ICC-profiles in the work of printing company we should pay a special attention to the fact that the efficiency and effectiveness of CMS is entirely depends on the stability of all the devices of the technological process from data input into a computer publishing system to final product output. Normalization of the technological process can guarantee such stability as well as following the standard which constitutes tolerances for color reproduction.

The process of characterizing the color reproduction devices is represented by diagnostic and establishing a connection between the hardware signals and the device-independent color coordinates. As a result of the characterization we can get a device profile.

To create a profile of the color reproduction device it is necessary to establish connection between device-dependent color space and device-independent space Lab for all grid points of a multidimensional LUT-table.

We propose to use the effective methods of forward and reverse color transformation for creating LUT-tables of profiles [5]. They allow reducing error during the process of transformation of color coordinates of images within the reproduction process.

For color information transformations in a computer publishing system it is necessary to have information about the input color device, i.e. a profile of this device, and the target output device profile to indicate the destination. Each profile contains data for the color transformation in the form of matrices, CLUT-tables and parametric curves, which allow us to define the color images in an open format. Open profile format allows us to embed profiles into any system compatible with the ICC standard. Since the various color management modules provide different result after conversion, one of the essential components for producing high-quality print production is to choose the method for converting the color information depending on the tasks of color reproduction technology [6].

Color management in the computer publishing system can be implemented in two ways: in applications specifically designed to perform specific tasks of color management and in the applications and device drivers using color management at the level of operation system. In both cases it is necessary to define the parameters of the device-dependent and device-independent working color spaces for each color model and a mechanism for their use. All the processes of color management can be divided into four main stages:

1. **Image input.** Input information of an image into a computer publishing system. The color information is recorded by input device (scanner, digital camera) and converted into a device-dependent color coordinates RGB of input device. In further processing of the original image for publication in accordance with the concept of device-independent color reproduction these signals are converted to device-independent coordinates Lab using the CLUTs of the input profile. For these conversions it is used CLUTs of the input profile and relative colorimetric rendering intent;
2. **Color correction.** During the process of color correction transformation of color information occurs within a color space Lab. In addition, for display the graphical information on the screen you need to connect the profile of the display device and to convert the device-independent coordinates to device control signals with relative colorimetric rendering intent;
3. **Conversion to output.** Creation of series of numeric values for reproduction the required colors on the output device. To carry out the separations of the file with layout in color space Lab we should to connect profile of an output device and to convert the device independent coordinates to CMYK;
4. **Soft proof.** It is needed to check the colors of the layout before printing. The system produces two color reproduction conversions: convert device-dependent CMYK values of output device to device-independent color coordinates Lab with absolute colorimetric rendering intent to simulate a paper color, and convert the device independent Lab values to device-dependent RGB color coordinates of color proof device with relative colorimetric rendering intent.

Therefore, in order to ensure accurate image reproduction process conversion between the colors of the device and device-independent color should be done with pinpoint accuracy. Active competition in the development of a various color management modules indicates that the current model of transformation, as well as a method of converting color data are far from perfect and requires a detailed analysis of all factors affecting the quality of operations of color transformations.

5. Formal description of the color reproduction process

To organize the optimal digital workflow between different parts of the printing system we need to develop an information model of the system. The process of developing an information model includes two stages. Namely, development of a system model and of a data flow diagram. This allows analysing and synthesizing an information about the different stages of the reproduction process and identify bottle neck. Modifying these stages we can achieve required quality of color reproduction.

The sequence of transformations of color information into a system is shown on data flow diagram (figure 4).

Formally, the color reproduction process can be described by a system model that includes structural, parametric and functional descriptions,as well as goal of the reproduction process [7]:

$$S = < X, O, v, \varepsilon, U, C, M, F, Q > \qquad (1)$$

$$\begin{cases} X = F(O,v,U,C,M), \quad X = \{L_i, a_i, b_i\}_{i=1,\dots,m} \\ O = \{R_i, G_i, B_i\}_{i=1,\dots,n} \\ v = \{v_i\}_{i=1,\dots,k}, \quad v_i = \{\Phi_i^j, \Psi_i^j\}_{j=1,\dots,3} \\ M = (M_1, M_2), \quad M_1 = \{\hat{X}_{w.p.}, \hat{Y}_{w.p.}, \hat{Z}_{w.p.}\} \quad M_2 = \{\beta(\lambda_i)\}_{i=1,\dots,N} \\ C = (\tilde{C}, \bar{C}), \quad \bar{C} = (\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)), \quad \tilde{C} = \{C_j\}_{j=1,\dots,N}, \text{ where } C_j = \{S_i(\lambda)\}_{i=1,\dots,34} \\ Q = P(X, X^*) \to \min\limits_X \end{cases}$$

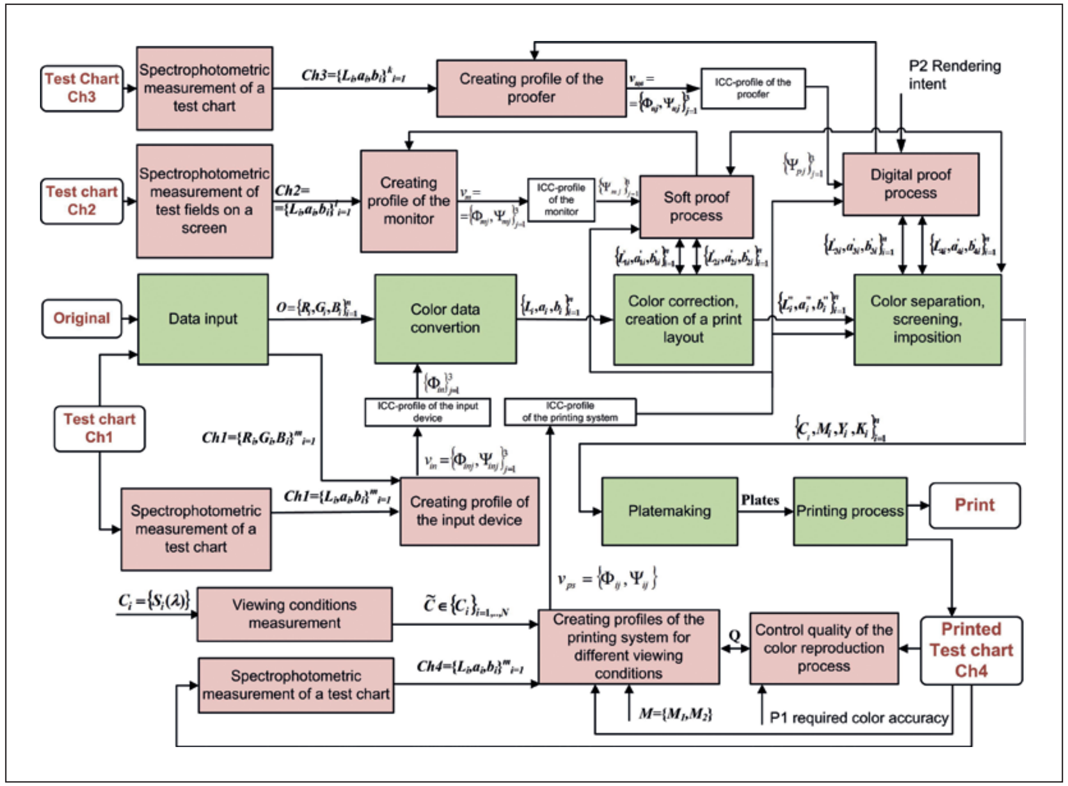

Figure 4: Data flow diagram

where $X = \{L_i, a_i, b_i\}_{i=1,\dots,m}$ is a set of coordinates of elements of the image, characteristics of the print;
$O = \{R_i, G_i, B_i\}_{i=1,\dots,n}$ is a set of coordinates of pixels of the image, characteristics of the original;
$v = \{\Phi_{ij}, \Psi_{ij}\}$ is the profiles of devices defined by a set of Φ_{ij} and Ψ_{ij} performing direct and reverse transformations between i-th device-dependent and device-independent color spaces for j-th color rendering intent; ε – error of color gamuts matching; U are parameters of a management: the operators of correction and conversion of the image gradations; C are viewing conditions of a print product (spectral characteristics or color coordinates of a "white point" illumination); M are characteristics of system "ink-paper" $M = (M_1, M_2)$ where $M_1 = \{\hat{X}_{w.p.}, \hat{Y}_{w.p.}, \hat{Z}_{w.p.}\}$

are color coordinates of a white point of paper, $M_2 = \{\beta(\lambda_i)\}_{i=1,...,N}$ is reflection spectrum; F is the operator describing technological process of color reproduction in color imaging system; Q is criterion of an estimation of quality of color reproduction. The aim of reproduction process is to obtain the required color on a print by solving the problem:

$$P(X, X^*) \to \min_X , \qquad (2)$$

where P is color difference, which is defined by the metrics ΔE in device-independent space Lab, and X* are desirable values Lab of coordinates of a print for the set type of illumination.

If investigate all the factors and limitations, which have an influence on the graphic data workflow in the digital systems, it has become possible to create the methods of creating CLUTs which will provide the basis for improvement of accuracy digital color data transformation for correct image processing.

In order to solve the problem, the multidimensional color look-up tables of profiles with a glance of actual viewing conditions of prints for color image reproduction and recording devices based on this model have been created [5, 8]. Different printing tasks require different methods of color reproduction. Namely, one may need to print some firm colors, to match the input images as closely as possible or to print some photos with memorable colors. Suggested information model realized corresponding color reproduction to obtain color appearance across different media and devices.

6. Conclusions

In time of intensive development and implementation of information technologies, computer and instrumentation technologies in the management processes it is necessary to provide effective joint equipment work of the entire printing company. That's why appear actual tasks of development and improvement of the various modules of the information management system to provide more accurate and predictable color reproduction.

The need for color management results from the possibility of producing variable system configurations combining differing individual components produced by different manufacturers. But implementation of ICC-management system in color reproduction performance of the printing company may be performed when work on the marketing and technological discipline has done, and formed an internal standard of the company, as well as the quality of the prints reproduction is controlled. It is necessary to determine just how precise a color match needs to be before they are satisfied. Improving accuracy costs money to purchase more accurate measurement tools. It takes time to perform calculations for creating ICC profiles that could provide more accurate digital prepress workflow.

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