UDK 681.32:778.6
Original scientific paper

COLOR MANAGEMENT IMPLEMENTATION IN DIGITAL PHOTOGRAPHY

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Abstract: *Digital cameras on the market today have a great potential to become the powerful tool for capturing images for use in all demanding fields (such as artwork digitalization), so many professionals started using digital technology. But, it is often the case, that it is necessary to spend a lot of time for visual editing and making color corrections in various software applications.*
In this research, some ICC color management techniques were used and tested to investigate the quicker ways to achieve digital images with improved color reproduction accuracy, without visual editing. A testing procedure for characterizing digital camera is described. This procedure is target-based, thus providing objective measurement of quality. The special color reference target for digital camera characterization was developed, applied and tested. The results show that using proposed methodology, the workflow efficiency and color accuracy can be improved.

Keywords: *digital photography, color management, color reference target, digital camera characterization, device profile, color reproduction, artwork digitalization.*

1. INTRODUCTION

Many prepress and graphic production experts today are using completely digital workflow that includes digital cameras as a source of color images, rather than conventional cameras and scanners. With including digital imaging technology in production workflow, the consumable costs are reduced and expensive scanning fees are eliminated. The capture format is immediately available for use in computer-based applications, considerably shortening concept-to-publication cycle times.

2. PROBLEM FORMULATION

The aim of the digitalization process is to capture the information from the original as accurately as possible. The more information that the reproduction contains about the original scene, the closer and more real the original scene appears.

It is important to accent that the total amount of information from the original scene cannot be increased after the image has been captured. It can only be redistributed in different ways in image-editing applications. Image processing can sometimes improve the information content of an image [3]. When an image has been degraded, for example: lose of sharpness, color inaccuracy; it is possible to employ algorithms that reverse the degradation, if enough is known about the way the image became degraded. Mathematical solutions of this kind can restore or enhance an image, and make it more acceptable.

Problem is that, correcting a defective image in image-editing applications is very time consuming and require experienced and technically skilled operator. That is why it is essential to start with a good image (with right tonal gradation, contrast, sharpness, and possibly with good color balance).

Another problem is that in today's production environment there are many different input (a wide range of scanners and digital cameras) and output devices (digital color printers, digital proofing devices, conventional presses, Internet). With so many different media and devices it becomes hard to achieve the desired consistency and color quality. Controlling the transformations required between different device color spaces, and ensuring that color reproductions are consistent across a range of different output devices, requires the use of a Color Management.

3. WHY COLOR MANAGEMENT

Color accuracy between the original scene and final output can be optimized using Color Management Systems (CMS). The term *color management* most often refers to the use of software to automatically determine the color reproduction characteristics of input devices, monitors, and output devices, and then to automatically make the image settings necessary for optimal color reproduction [4].

It could be said that Color Management attempts to simplify color reproduction by putting color expertise and science into software. Much as desktop computers changed publishing, color management attempts to make color adjustments automatically so that less technical or experienced users can reproduced color, on different devices, more easily and accurately.

Color Management is a collection of utilities and resources for calibration and automating color conversions between all input and output devices within an image processing chain, with the aim of achieving the desired color reproduction independent of the devices used. It is now an established methodology that can give acceptable results in achieving the best available color match between originals, monitor displays and printed output. It gives users a basis for greater control over the reproduction process. But, it is also an evolving methodology, because of continual advances in the techniques used to map colors between different systems and media.

3.1. ARCHITECTURE OF COLOR MANAGEMENT SYSTEM

The architecture of a Color Management System incorporates two basic components: profile and color management module (CMM).

A device profile defines the characterization of each device used for input and output of color. A profile for the device is created by typical methods like: three-dimensional CLUTs (color look-up-tables) with interpolation and extrapolation [5], least squares polynomial modelling [7] or neutral networks [8], which adjusts the device's color values in order to produce an accurate reproduction of the captured image.

The second basic component, a color management module (CMM), is a digital-signal-processing "engine" for performing the actual processing of image data through profiles. It connects together profiles to produce transformations for any group of devices, using the profile connection space (PCS) as the device-independent standard color space based on the CIEXYZ color space. Metaphorically speaking, the PCS acts as an "adapter" between the profiles of the input and output devices.

3.2. THE IMAGE REPRODUCTION WORKFLOW USING COLOR MANAGEMENT SYSTEM

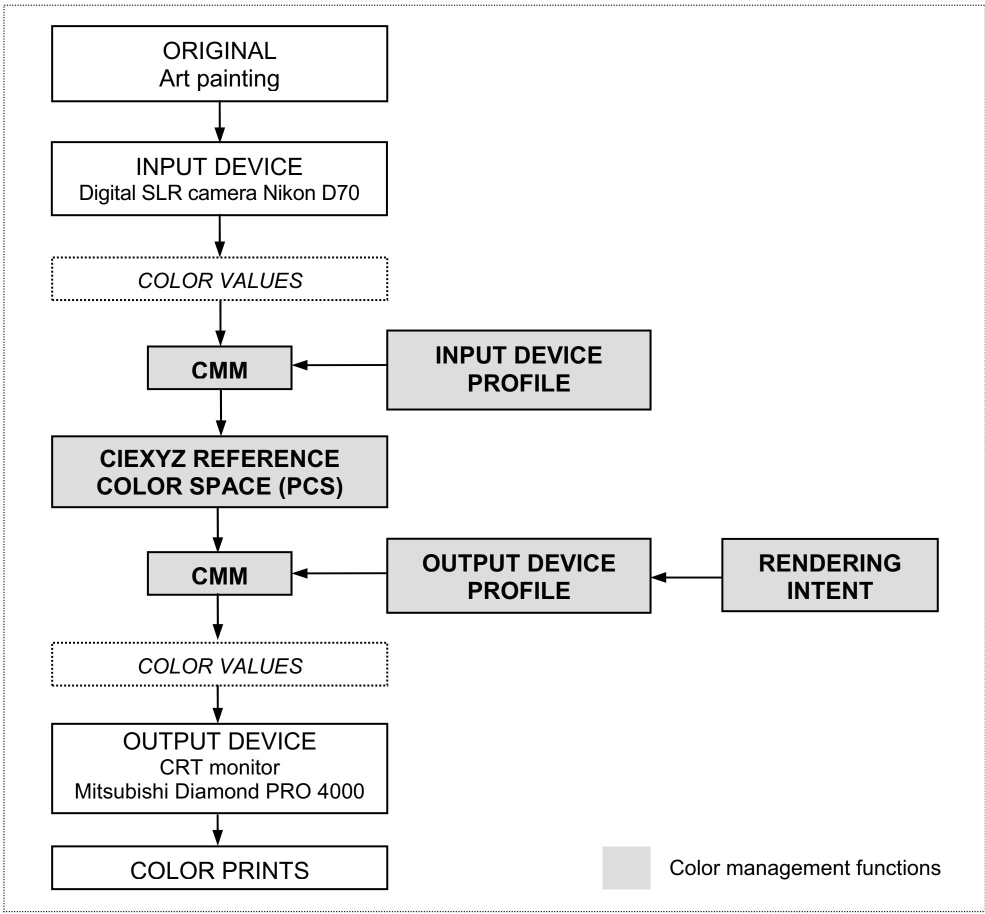

Figure 1. Image reproduction workflow using CMS

The image reproduction process using Color Management System (Fig.1) involves several intermediate steps inserted between the input and output color values:

1. The RGB values of the input device are converted into device-independent color values (CIE XYZ or CIE L*a*b*) with the aid of the color profile for the input device and conversation software - CMM. In this form the image values may be used for any output processes or devices.
2. When the process for outputting the image has been established, the color values of the image are converted into the process-specific output color values with the aid of the color profile of the output device and the same conversation software (CMM). The output profile contains the desired reproduction strategy, called *rendering intent*, the

way the color management system maps the color of an input image to the color gamut of an output device. There are three types of rendering intent: perceptual (for images such as photographs), colorimetric (for special colors - typical example of this is the company logo) and saturation (for so-called "business graphic").

4. IMPORTANCE OF A DIGITAL CAMERA PROFILE

The reason why to use Color Management in digital photography and to create a camera profile can be easily explained by following. Digital cameras reproduce colors like a scanner, using color filters put as a mosaic in front of the sensor. To get color accurate digital image of original scene, spectral sensitivities of those filters should closely resemble human visual system's spectral sensitivities. But, because the colorants which can be used for color filters in digital cameras are very limited, it is not possible to produce the same spectral sensitivities as those of the average human observer. This mean, that digital cameras create more or less color errors, depending on the sensor and the filters. These errors can be corrected using a digital camera profile.

4.1. COLOR SPACE PROFILES VS. INPUT PROFILES

There are two kinds of ICC profiles that can be applied to image files created by digital cameras: working color space profiles and input profiles [6].

When a camera is producing image files that contain standard color encodings (working spaces), such as sRGB, Adobe RGB (1998), or ProPhoto RGB, it is performing the color rendering. In this case the image encoded does not represent the scene, but rather the camera's attempt to create and encode a pleasing reproduction of the scene. These encodings are called "standard output referred", since they encode the colorimetry of the image on a standard output reference medium [3]. The choice of working color space is depending on the intended usage of image in future. In the case of sRGB, the reference medium is a standard CRT monitor, and in the case of ProPhoto RGB, the reference medium is the high quality reflection print (on photographic material) with perceptual intent. The profile is made using the rendered data and assigned to the images using software like Adobe Photoshop. The data is usually in 8bit, JPEG or TIFF, and a color space transformation into a previously mentioned working space has been made by the camera, limiting the possibilities of color corrections.

In special cases, like reproduction photography and product photography, where digital image is supposed to exactly match the original captured, those standard color space profiles (matrix profiles) are not adequate solution. The better solution is to assign the profile to a raw "scene referred", not rendered, 12 to 16 bit image data. Raw data has the advantage that the high bit depth allows to correct for exposure level, white balance, sharpness etc. without a significant loss in image quality. Compared to the analog photography a raw file corresponds to a negative film. The most often the raw image data results from capture using a color filter array (RGB) a special camera raw processing application is needed to create a viewable color image. In most cases, these applications create standard output referred images, as would the camera. But the difference is that the color processing can be done by user, after the image is taken, eliminating the losses that result from incorrect white balancing or color rendering.

It must be noted that profile making applications can only handle TIFF and JPEG files, so raw files from the camera have to be converted into these RGB formats. Also, it is important to point out that a profile made for a given lighting setup is only valid for images taken under the same conditions.

5. EXPERIMENTAL WORK

In very demanding field, such as artwork digitalization, the object color matching is the reproduction goal. The purpose of this research is to propose a new solution to the problem of color accurate reproduction. The solution involves implementation of Color Management in image reproduction workflow. Contribution of this research is in developing and using custom made color reference target for precise digital camera characterization.

5.1. CREATING A DIGITAL CAMERA PROFILE

The method for device characterization (process of creating the profile) used in these research is method based on color target. Creation of a camera profile starts with choosing a color reference target (characterization target). Color samples from target are then measured with spectrophotometer, or previously measured data - target description file (TDF) accompanying the standard target can be used. The target is then photographed by the camera, delivering RGB values to the profile-building stage. The relationship between RGB and XYZ is derived and a device profile is created.

From previously studied researches [10, 11, 12, 13, and 14] and personally conducted experiments [15], it was found out that the color accuracy of the digital camera is considerably impacted by the choice of the color reference target used for characterization process. Ideally, color targets should span the color range of imaged objects and have similar spectral properties (made using similar colorants). For photographic and printed materials, standard targets are available. The problem is that for art objects (such as paintings), such targets are largely nonexistent [2]. When characterizing digital camera for capturing art paintings, the standard targets are used, resulting in unacceptable differences in reproducing some special colors, so lots of time must be spent in visual editing and color adjusting in various software applications. To avoid the need for excessive color editing, and to improve workflow efficiency and color accuracy, the custom color reference target for digital camera characterization is developed, applied and tested in these research.

The objects for digitalization process in this research were paintings made with gouache paint. For this purpose, the color target was made using the same colorants and same paper as those on paintings being photographed. Target was named CGRT24 - Custom Gouache Reference Target, with number 24 representing the number of colour samples.

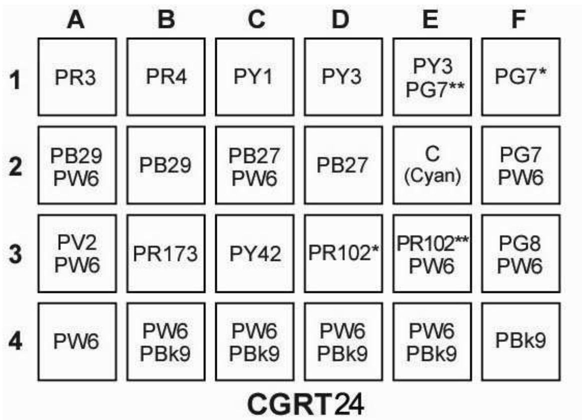

Figure 2. Custom Gouache Reference Target, with a list of used pigments

After creation, the samples on target were measured using GretagMacbeth Spectrolino spectrophotometer. The CIELAB values for each color sample were taken by averaging three measurements from a spectrophotometer. Measured values were saved in target description file in ProfileMaker PRO 5.02 application.

The target and paintings was photographed in controlled studio conditions. Illumination used was tungsten with correlated color temperature of 3200K. Image captures were performed with Nikon D70 digital camera and AF Nikkor zoom lens 35-70mm f /2.8. Exposure mode was manual. Sensitivity of the system was set to ISO 200. There was not any signal processing such as gamma correction, hue adjustment, sharpening or noise reduction during imaging.

Captured image of target (TIFF format) was then supplied to the ProfileMaker software; witch relates camera RGB signals to measured CIEXYZ or CIELAB values from target to build a CLUT based transformation structure. The profile was made for used digital camera, for a given lighting setup.

To be able to objectively compare the results of characterization done with developed CGRT24 target, the standard GretagMacbeth color target ColorChecker (with 24 color samples) was also used for characterization.

Profile made with our custom target was named CGRT24T (T stands for tungsten illumination), and profile made with standard GretagMacbeth color target was named GM24T.

5.2. EVALUATING A DIGITAL CAMERA PROFILE

The evaluation of profiles created from those targets was conducted using calibrated CRT monitor (Mitsubishi Diamond PRO 4000) as a soft proofing device. The profiles were evaluated by testing of profile accuracy in predicting the colors from original painting.

Test was conducted by choosing 24 different colored areas from digital image of painting. Those colors were formed in samples and save as untagged digital file (without profile). Those areas were measured directly from original painting (using mask with holes at exact coordinates), and compared with values of color samples with assigned profiles (CGRT24T and GM24T), measured from monitor. On Fig. 3, measured color areas are shown.

Color differences (ΔE^{*94} and ΔE^{*00}) for every profile were calculated and compared. Results from image files without profiles, will also be compared with those made with profiles.

Figure 3. Measured color areas of a painting

6. EXPERIMENTAL RESULTS AND DISCUSSION

The profiling evaluation results are shown in Table 1. From the obtained results, it can be noticed that the average color errors are smallest on digital image with profile CGRT24T assigned.

Table 1. Colorimetrical accuracy of input profiles

Original painting	ΔL Average	ΔC Average	ΔH Average	ΔE_{94} Average	ΔE_{00} Average
Without profile	7,59	-7,72	7,57	11,78	10,87
GM24T	-0,04	-4,07	5,00	5,64	6,10
CGRT24T	1,00	-2,85	5,36	**5,08**	**5,56**

Currently the most important color space based on the opponent-color theory is known as CIELAB. The goal of the CIELAB color space design was to have perceptually uniform color differences throughout the space. L* represents lightness, a* approximates redness - greenness, b* approximates yellowness-blueness, C^*_{ab} approximates chroma and h^*_{ab} approximates hue. The chroma is varied as a parameter from the center to the edge of the circle, hue from 0° to 360°, and lightness from 0 to 100.

Color differences are measured in the CIELAB space as the Euclidean distance between the coordinates for the two stimuli. We calculated two color differences, ΔE_{94} and ΔE_{00} in order to compare which one is better agree with visual assessments.

The CIE94 has hue weighting function S_H which is independent of hue angle. The CIE94 equation (1) gives large errors in predicting chromatic differences for saturated blue colors and wrongly predicts chromatic differences between neutral colors [1].

$$\Delta_{94}^{*} = \sqrt{\left(\frac{\Delta L^{*}}{k_L S_L}\right) + \left(\frac{\Delta C_{ab}^{*}}{k_C S_C}\right) + \left(\frac{\Delta H_{ab}^{*}}{k_H S_H}\right)} \quad (1)$$

where

$S_C=1+0,045C^*_{ab}$

$S_H=1+0,015C^*_{ab}$

The CIE have recently recommended for trial the CIEDE2000 (ΔE_{00}) color difference formula that is given by equation (2) [9].

$$\Delta_{00}^{*} = \sqrt{\left(\frac{\Delta L^{'}}{k_L S_L}\right)^2 + \left(\frac{\Delta C^{'}}{k_C S_C}\right)^2 + \left(\frac{\Delta H^{'}}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C^{'}}{k_C S_C}\right)\left(\frac{\Delta H^{'}}{k_H S_H}\right)} \quad (2)$$

The ΔE_{00} include not only the lightness, chroma and weighting functions, but also an interactive term between the chroma and hue differences for improving the performance for blue colors and a scaling factor for the CIELAB a* scale for improving the performance for colors closed to the achromatic axis.

Perhaps more important than the average color differences are the directions of color error shown as a vector plot in CIELAB color space at Fig. 4, Fig. 5 and Fig. 6. Color values measured from original painting are presented with circle and values measured from digital image of painting on monitor are presented with triangle. Errors whose directions are along lines of constant hue angle correspondent to errors in chroma.

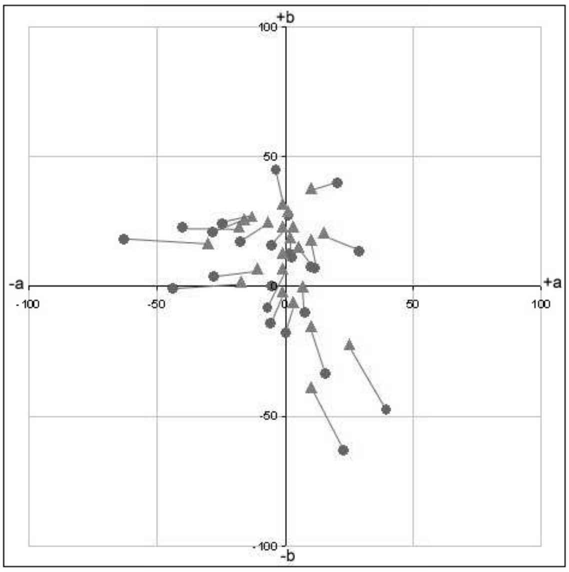

Figure 4. Without profile

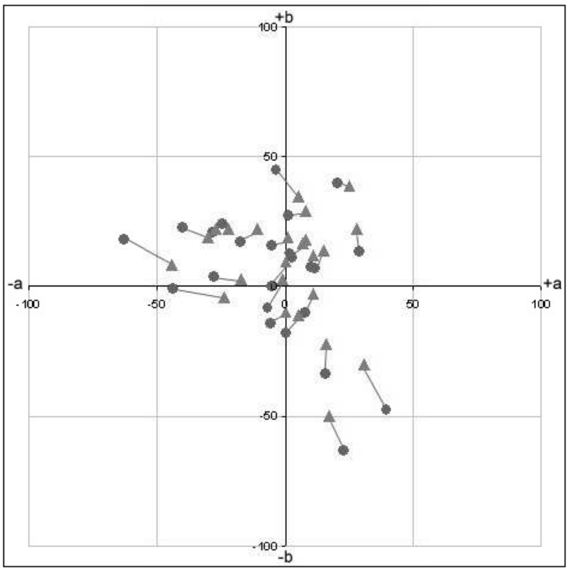

Figure 5. With GM24T profile

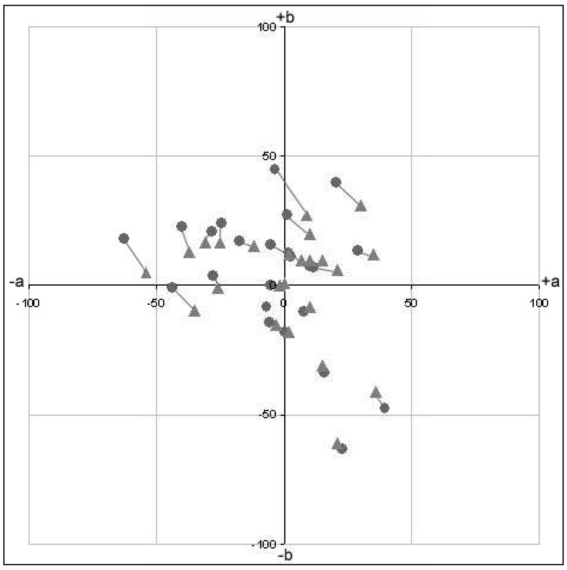

Figure 6. With CGRT24T profile

The largest errors in chroma are present in images without profile. In those images, there are also large hue errors present (Fig. 4). In images with assigned profiles, all errors are smaller.

Image with CGRT24T profile assigned has smallest color differences (Tab. 1). Also, the chroma of original painting is best preserved on image using CGRT24T profile.

7. CONCLUSION

The results show that by implementing ICC color management techniques it is possible to achieve digital images with improved color reproduction accuracy, without visual editing.

The results also showed that the differences in the colorants (pigments) used and different surface characteristics of the color reference target used for camera characterization may contribute to the color difference. In order to improve the accuracy of digital camera color reproduction the color reference target, used in the characterization process, should ideally be made from same materials (colorants and surface) as those used on objects being photographed. Some degree of accuracy can be maintained if the materials and surface textures have some similarities. Otherwise, the conversation from device dependent signals to device independent attributes will not be accurate.

Also, it is expected that the performance of digital image capture can improve using different lighting and more complex color processing, which will be the subject of our future research.

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Received: 10 September 2007
Accepted: 29 October 2007