Application of color management to display devices

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Color Management promises to achieve the same color display of an image on two or more different monitors just by using the appropriate ICC profiles. Tests at EMPA have shown that this goal is not easily achieved.
As with any other device, which will be characterized with ICC profiles, the monitor must first be calibrated. Monitor calibration is not an easy task. As a result, the main objective of this paper is to shed some light on the issue of monitor calibration.
This paper discusses only CRT's (Cathode Ray Tubes) because at the moment no calibration tools (measuring devices together with software) for LCD's (Liquid Crystal Display) are available.

Color Appearance Modeling

One limitation to the attainable precision of a calibration and characterization lies in today's color appearance models. CIELAB as well as several other color spaces have no possibility to describe the result of the perception of a color if the surround changes. This has important implications if a user wants to compare an image on a monitor with its original or reproduction in a light booth having a different illuminant or background.

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CIE has worked out a new color appearance model (CIECAM 97) with which such questions are resolvable. Until recently the industry had to work in the CIELAB color space and therefore some problems could not be solved.

Importance of the monitor in tomorrows workflow

With the increased use of digital information and its transmission from customers to printing plants over important distances, the proof will no more be the control instrument of preference to answer color quality questions. It would take to much time to send proofs around the world. Therefore, in the future the monitor will become the central quality control instrument, therefore proper calibration and characterization is very important.

What are the operating parameters of a monitor?

As previously mentioned, the principal goal of this paper is not to explain how a CRT works, as there are many appropriate explanations already published, but to present some of the issues which must be addressed to in order to obtain a properly calibrated and characterized display.
To set two monitors to the same status of operation the following parameters have to be set properly:

- Black point
- White point (luminance and chromaticity)
- Gradation (gamma)
- Monitor surround (ambient light condition)

These parameters are related to many parts of the monitor and the connected computer. The parts involved are the cathode ray tube, the amplifier in the monitor, settings on the monitor, the video card and the LUT (Look up table) on the video card. When a monitor and a computer are purchased, most of these parameters are fixed for the first period of time as they will undergo change with age. Through software it is possible to change the information in the LUT on the video card thereby altering the appearance of the colors on the monitor. If the user doesn't carefully supervise the LUT, consistent results may be difficult to obtain.

Black point

If a monitor is not in operation, the tube is black. This is the darkest color, which can be obtained with a monitor. There are different blacks on different monitors. Some suppliers call their products names such as «Black Trinitron» or other similar names. Such monitors are suitable for the purpose of "soft proofing".
The other parameter, which is related to the black point of a monitor, is the cut off point. This point describes at which voltage the first visible tone above the black is rendered. This point should be as close to the black point as possible. But as in printing no lightness values less than about $L^* = 10$ are reachable under standard conditions. Therefore, a monitor is suitable for soft-proofing if the cut off point shows a value of L^* (CIELAB) lower than 5.

White point

The white point of a monitor is very crucial for two reasons: it defines the color of the white and the achievable contrast of the monitor. To obtain a good white, the monitor must be able to emit a certain level of energy otherwise the human visual system will not perceive the impressions of white. On the other hand the energy of the white point can't be set to high, because there are factors, such as monitor type, size and age, which limit the reachable level of energy. Dr. Robert Hunt and others have reported that the human visual system needs some energy to be able to have a real white sensation after a short adaptation period. This is at a luminance level of about 85 cd/m^2. This number is reachable by most of the monitors but only when they are new. To use a monitor over a period of about three years, an appropriate setting is at 70 cd/m^2. Experience indicates that a luminance level of approximately 70 cd/m^2 is sufficient to lead to a real white sensation. On the other hand, experiences are such that settings at higher energy levels can lead to eye fatigue when working for a period of eight hours or more in addition to decreasing the life span of the monitor. Therefore a setting of 70 cd/m^2 is recommended.
The specification for the chromaticity of the white in the graphic arts industry is D50. Therefore, if a monitor is used in a pre-press environment D50 is the correct color temperature setting. For other applications the white point should match another standard daylight such as D65 for example. This applies to viewing movies, multimedia products or the Internet.
The following values were found through measurements:

color temperature setting (K)	measured color temperature (K)	measured luminance (cd/m²)
Undefined	8500	80
9300	8000	72
6500	5800	65
5000	4000	55

Table 1: Measured and averaged color temperature and luminance values on used monitors without calibration

color temperature setting (K)	measured color temperature (K)	measured luminance (cd/m²)
6500	6700	65
5000	5200	55

Table 2: Measured and averaged color temperature and luminance values on monitors used after calibration (the calibration tool wanted to set higher luminance values, but the monitor was not able to supply them.)

color temperature setting (K)	measured color temperature (K)	measured luminance (cd/m²)
-	11000	130
9300	9000	115
6500	6800	100
5000	5500	90

Table 3: Measured and averaged color temperature and luminance values on new monitors without calibration

After calibration the new monitor shows the settings established by the calibration tool.
The measurements were taken with a Minolta Spectroradiometer Model CS-1000. The calibration was done with Alwan Monitor Expert Calibrator.
The chosen luminance of about 70 cd/m^2 for the monitor setting will influence the illuminance level, which will be used in the light booth for comparison with the monitor image. In order to make an accurate comparison between the monitor image and the hardcopy, the illuminance level in the light booth, which is measured in lux, should be equivalent to the luminance level of the monitor, which is measured in cd/m^2. If there is no specular reflection involved the following formula can be used to calculate illuminance from luminance.

$$\text{Illuminance (lx)} = \text{luminance } (cd/m^2) \ / \ 0.318$$

This means that the light booth next to the monitor should be set to approximately 75 / 0.318 = 235 lx. The ISO-specification 3664, which describes the conditions for color comparisons in the printing industry, describes two cases of which neither fits this monitor - original or monitor - print comparison case. This case should be further investigated and described in this standard.

Gradation

With the setting of the black and the white point the dynamic range of the monitor is established. Now it is important to set the mid-tone reproduction too. Like in tone reproduction a gradation curve has to be evaluated and set for each monitor. There is a curve for each of the three monitor guns R (red), G (green) and B (blue). These curves are called gamma. The gamma is the exponent in the formula, which describes the relation between the input (electrical power) of the monitor and the emitted luminance.

$$\text{Luminance} = \text{Power}^{\text{Gamma}}$$

Today's CRTs are produced such that their uncorrected gamma is at a value around 3. If a monitor is used as a soft-proofing device, the gamma has to be set to the value, which lets the mid-tones be reproduced the right way. To do so, the ambient light conditions have to be taken in account. If one looks at a monitor in a dark room, the colors, especially black and dark colors, on the monitor are seen lighter. If one looks at a monitor in lit room conditions this effect is not that strong. Therefore two different gamma are used in today's world. If one looks at images in dark rooms (like movie theaters) the used gamma is 2.2. Because the surround of the image is dark, dark parts of an image tends to be seen lighter. Therefore this gamma makes them darker to compensate this dark room effect. If the images are looked at lit surrounds, the dark parts of the image are darkened. To light them up the gamma has to be below the value of 2. For such conditions a gamma of 1.8 is normally used. With the initial setting at a gamma of 3 all images would look to dark.

The color gamut of a monitor

The colors a monitor is able to display are primarily a result of the red, green and blue phosphors used. These three colors (phosphors) greatly influence the color gamut of the monitor. There are standards for the colors of the monitor. In Europe the Pal system is widely used while in America the NTSC specification is used. Unfortunately the calibration tools don't judge the colors and compare them to the specifications.

Monitor surround

Because the human visual system is able to view a monitor image in the same way as an image in a light booth, the surround of the monitor is very important. One aspect of the surround is the color of the border of the monitor. Normally this border is white or a light beige. This leads the human visual system to see the monitor image as too dark. The border of the monitor should be about 20% of the maximum luminance of the monitor image. Since the maximum luminance is set to 70 cd/m^2, the illuminance of the monitor border should not be higher than 50 Lux (70 cd/m^2 / 5 / 0.318 = 45 lx).
The same value should be applied to all other things around a monitor. For pre-press work the room should be indirectly lit. The amount of light should be below this 50 Lux and of a color temperature of D50.
If the monitor is used to display movies or related things, they should be looked in a dark room like a movie theater. The monitor border should be black too, as the other things around the monitor should be.

Calibration methods

Research indicates that there are three methods by which a monitor can be calibrated. They are:

- Visual methods
- Combined methods
- Instrumental methods

Visual methods

Visual methods are widely known and used in the pre-press industry. A popular product is «Adobe Gamma», which is supplied with every copy of Photoshop 5.0. Practical tests with such methods and different users have shown that a deviation between a color value in a file and its reproduction on the monitor is a ΔE of about ± 20. Such calibration is far from being suitable for color correction and soft-proof stations. The surround of the monitor is not considered by these calibration methods.

Combined methods

There are methods by which the black and white point of a monitor are set by visual comparison while the gamma setting is done through instrumental measurements. The lighting conditions at the monitor surround are not measured. A popular product in this category is «Color Partnership's Optical». Practical tests with several users have shown that color deviations of ΔE-values of ± 10 are normal. Such calibration methods have some value but are not recommended for soft-proof stations.

Instrumental methods

If a tool is able to measure all the variables of a monitor and set the correct values color deviations of approximately ± 3 ΔE^* value can be obtained. Such a tool is »Alwan Color Expertise Monitor Expert Calibrator». This tool even measures the surround light conditions of a monitor. With such small color deviations between a color value in the database and its reproduction on a monitor the highest possible precision is reached.

How the tests were done

The different monitor calibration tools use different measurement instruments. To assess the precision of the measurements of these different instruments a more precise instrument was used (Minolta CS-1000 Sprectroradiometer). With this instrument colors are measurable over a distance from the monitor. The color in a light booth is also measurable.
Instruments used by the various calibration software include:

- Gretag Specrolino
- X-Rite DTP 92
- Sequel Colorimeter

Even the least expensive of the instruments used, the Sequel Colorimeter, when used together with appropriate software measures with a high precision. All of these instruments are suitable to use together with monitor calibration tools.

Monitor characterization

After a monitor is calibrated an ICC-profile has to be made in order to characterize the device. All the calibration tools mentioned are able to generate an ICC profile just after the calibration is done. It's clear that the more sophisticated the calibration method is, the better the resulting profile will match the underlying calibration standard, which is D50. If the user wants to create the profile with one of his profile generating applications it is possible to do so.
The above mentioned ΔE-values are the result of the combination of calibration and characterization with the same tool.

The problem with the video card

The result of a calibration and characterization of a monitor is stored in the LUT (Look up table) on the monitor card. This LUT is open to any software, which has some functionality to clear or alter this LUT. Therefore a user of a computer never knows exactly which status the LUT has. There is no known software available, which would help the user to keep control over the LUT on the video card. The only software, which was found to help in this respect, is Alwan Color Expertise's MEC spy. This software hides the LUT so that no software is able to alter anything until the user wants to change the information in the LUT. Many computer users don't know of the existence of this LUT and therefore have no explanation of their problems with the accuracy of the used monitor.

Summary

In the future the monitor will be an important quality control instrument, because soft proofing will become more widely used. To do soft proofing under controlled conditions it is necessary to calibrate and characterize each monitor in a daily interval.
Today the instrumental monitor calibration is almost unknown. This will change very rapidly over the next two years, since many important monitor calibration devices (hard- and software) will come to the market, which are affordable for every pre-press and printing company.