ICC profiles for Color Definition on Displays

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Abstract

Monitors are used more extensively as a soft proof for faster reproduction and for networked production environments. The International Color Consortium has done a great service to the graphic arts industry by defining the technical property parameters for various devices that carry color information. However ICC does not define every detail needed for color reproduction. One reason for this could be that it is difficult to standardize all the details for practical use on the monitors, or there is a need to keep the technical definitions simple and expedient.

Color rendering of phosphors, defined as an RGB color with CIE-XYZ co-ordinates and the gamma function, are compared with different lighting conditions in this study. The claimed ideal color rendering performance of the monitor phosphors is checked and compared with the print quality deviations. Also the absolute brightness values of the monitors are compared with the brightness values of the graphic arts standard viewing booth.

The sufficiency of the ICC specification for color definitions is estimated by measuring the monitors with a radiometer. The measured color values include the surrounding light reflected from the surface of the screen. Different monitors are measured in various lighting environments and the results are reported.

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Introduction

The monitor was previously regarded as an unreliable tool for proofing. However networked production and CTP output, among other technical changes make the monitor in some cases the only possible method for forecasting the final output.

An interesting area of research for proofing is the human visual research where the monitor is frequently used as a tool to study human visual systems. The latest results with the visual research methods and the algorithms show that the monitor can be an adequate tool also for proofing. This paper evaluates the details needed for color matching on displays with color management tools.

Although the monitor manufacturers standardize the color of monitor phosphors and the gamma, individual differences between the monitors are quite remarkable. Also the users influence on final output by adjusting the contrast and the brightness according to their own subjective estimations. Figure 1 gives the color coordinates for eight Nokia 447B monitors in the CIE-xy diagram. The white points differ remarkable from default white point setups and the RGB CIE-xy- values also show differences that introduce errors over 10 ΔE units in CIE-LAB space.

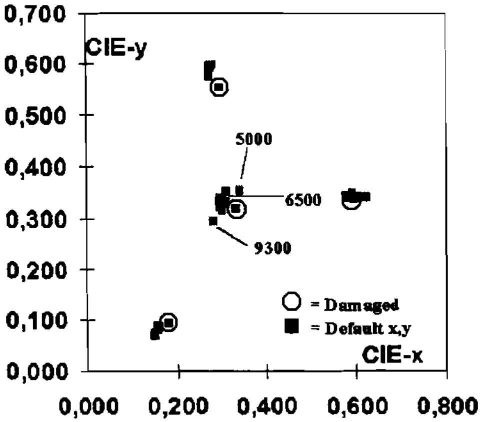


Figure 1. Eight Nokia 447B monitors with their phosphor coordinates in the CIE-xy space.

The selected monitors were not calibrated for any conditions. Instead, the color measurements were also samples of different types of usage of monitors. So Figure 1 rather represents the real usage of the monitors in addition to their physical differences. Carefully calibrated monitors would give a better match to the values of the specifications. However, monitors own white point settings did not guarantee the consistency of the white points between monitors, which was checked with a spectroradiometer.

Definitions or instructions not included in the ICC standard

ICC tags describe the basic parameters for defining color rendering on color displays. The color coordinates of the RGB phosphors and the gamma for all three channels have their own tags in the ICC specification (Table 1).

Table 1. ICC tags for color displays[2].

Tag Name	General Description
profileDescriptionTag	Structure containing invariant and localizable versions of the profile name for display
redColorantTag	Relative XYZ values of red phosphor
greenColorantTag	Relative XYZ values of green phosphor
blueColorantTag	Relative XYZ values of blue phosphor
redTRCTag	Red channel tone reproduction curve
greenTRCTag	Green channel tone reproduction curve
blueTRCTag	Blue channel tone reproduction curve
mediaWhitePointTag	Media XYZ white point
copyrightTag	7 bit ASCII profile copyright information

The color values are first linearized, and then calculated by a matrix transformation with colorant tag values:

$$\begin{aligned} linear_r &= redTCR[device_r] \\ linear_g &= greenTCR[device_g] \\ linear_b &= redTCR[device_b] \end{aligned}$$

$$\begin{bmatrix} connection_X \\ connection_Y \\ connection_Z \end{bmatrix} = \begin{bmatrix} redcolorant_X\, greencolorant_X\, bluecolorant_X \\ redcolorant_Y\, greencolorant_Y\, bluecolorant_Y \\ redcolorant_Z\, greencolorant_Z\, bluecolorant_Z \end{bmatrix} \begin{bmatrix} linear_r \\ linear_g \\ linear_b \end{bmatrix}$$

Only the CIEXYZ space uses the matrix/TRC models. If the color values are passed with CIELAB values, multidimensional look-up tables are used [2].

Considering the typical use of the monitors, their age, their prone to drift from the calibration setup and the different qualities, the interpolations through CIELAB encoding might give a better match for color. On the other hand the sRGB, proposal and its definition for Internet delivering the CIEXYZ encoding seem to be some kind of a default convention.

A conventional hard proof under standard viewing conditions should match the monitor proof. However, standard viewing conditions are not always available, and the other viewing and lighting conditions need to be taken into consideration. The ICC standard does dot define every detail for more accurate characterization and calibration of the monitors under different viewing conditions. Some of the missing definitions or recommendations are:

1. Ambient light adaption.
2. Adjustment of the monitor brightness and contrast.
3. Monitors' white selection order with other adjustments.
4. Monitors white selection effects on RGB color CIE-xy coordinates.
5. Preferable white selection considering the achieved brightness.
6. How to use other monitor linearization or calibration software with the CMM.
7. How to handle inhomogeneity of monitors' brightness values over its surface.

The ambient light has been excluded from the ICC public definitions but there are cases where the images are viewed under some kind of lighting. Practice has shown that the images are not always produced and rendered in a digital darkroom, and the color definition are checked with conventional techniques, for example by checking the percentage values of the color. Visual assessments of the images from the monitor are not used.

Monitor structure

The monitors' color rendering characteristics result from their general structure and techniques. Also the monitors' ability to produce the required colors is dependent on the video boards. Between the video signals and the monitors EIA (Electronic Industrial Association) has defined voltage scales for D/A-circuits. However, the standard allows so much tolerance that the color accuracy is not guaranteed. This means also that the manufacture given color coordinates or gamma values do not necessarily show the real values, and the monitor should be characterized with the video board.

The monitor reproduces the image from the signals given by the video board. These signals are amplified and the deflection jokes drive the electric beams on to the surface of the monitor. The beam accuracy to hit the required phosphor dot is ensured by the shadow mask or by the aperture grille.

In general the electronic beams that pass through the aperture grille yield brighter images but the beams hit more accurately to the required phosphors with shadow mask, which usually increases channel independence [7].

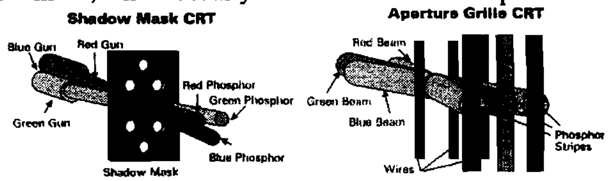


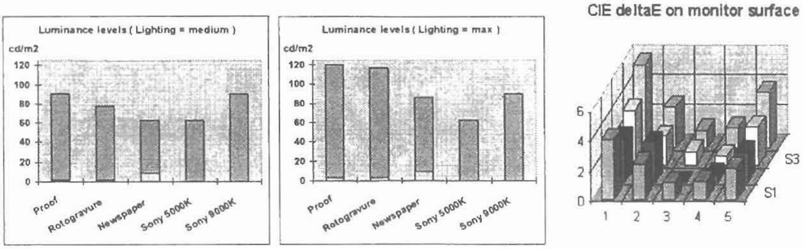
Figure 2. Shadow mask (a) and aperture grille (b) [7].

The phosphor dot resolution is one of the quality parameters. With both techniques dot resolutions is about the same. The shadow mask may show sometimes moiré effects. If the monitor gamma is estimated with some visual tests, the phosphor raster lines orientation to the beam direction has an essential affect on gamma values.

The monitor's stability and tone rendering

The monitor's instability is the common argument ignoring it as a proofing solution. The luminance changes over the time and the spatial variations on the monitor surface are sometimes clearly over 8-10 ΔE in the CIE-LAB space (Figure 3-c). Usually the luminance values are lower along the edges of the monitor. The human eye is, however very adaptive to spatial luminance changes [8].

Electronic guns do not always have the accuracy of an ideal additive color mixture and place and channel independence is not always achieved. The age of the monitor usually increases the short time instability but the continuous electronic beam scan over the phosphor surface does not affect its ability to show pure color immediately. The thickness of the phosphor surface keep its dimensions over longer period of time. In a short time monitor will change the brightness because of the poor power supply or due to the slowly increasing heat.



(a) (b) (c)

Figure 3. Different levels of luminance for the monitor and the viewing booth (a,b) and varying luminance on the monitor's surface (c).

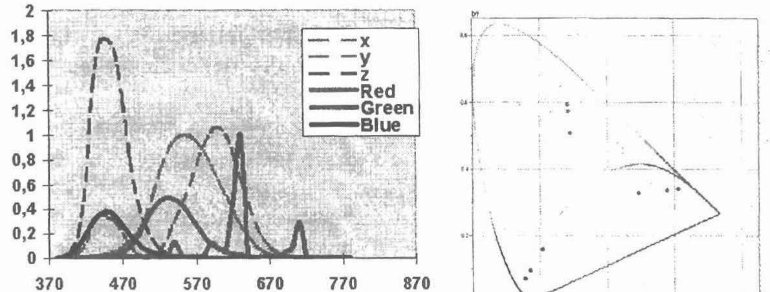
The monitor's tone rendering is mostly driven by the gamma function. Its shape is different from the graphic reproduction s-curve tone rendering. This is not a problem if the gamma function for the different guns or channels is well known. Instead, the dynamic range of the absolute brightness values compared with European graphic arts standards, causes difficulties with the monitor proofing. Monitors cannot reach 2000 lux (± 500 lux) illuminance, which is 637 cd/m^2 and defined in standard ISO 3664 for the viewing booths in graphic arts. ISO 13655 defines new values for the lighting conditions where the illuminance is 500 lux and the corresponding luminance is 150 cd/m^2. The monitor's luminance usually varies in the range of 70-120 cd/m^2 and may be strongly dependent on the white point setup. The typical range of luminance is slightly below the ISO 13665 standards 150 cd/m^2. However, the reflection from the paper is about 80 % approaching the monitor's maximum luminance values of 120 cd/m^2 .

The white and the black points of a proof, a rotogravure print and a newspaper print were measured under different luminance levels. In the viewing booth the illuminance of the light could be adjusted freely to the different levels. The depicted Sony GDM monitor (representing the average monitor in this study) has some difficulty in reaching the 120 cd/m^2 luminance especially when the white point was chosen to be the standard D50. However, the luminance range of the simulated newspaper on the monitor fits in the "medium level" luminance ranges of the newspaper in the viewing booth with both white points (9000K and 5000K). In the viewing booth the black point of the newspaper was higher compared to the monitor's black point in the darkroom Thus the monitor proofing of the newspaper could be possible in the ambient light to some degree of illuminance.

Monitor as on ideal color production system

The monitor color rendering capabilities can be viewed by means of the spectral emissions of the phosphors and the color coordinates in the CIE-Yxy values. When comparing the spectral emissions of the monitor's phosphors with the CIE color-matching functions, which represent the sensitivity of the human eye over different wavelengths, the emission of the red phosphor is narrower and more intensive than that of the green and blue phosphors (Figure 4).

The wavelengths of the RGB –phosphors' emission spectra most intensity parts locate with a slight difference to the most sensitivity wavelengths of the human eye. Red phosphor has two peaks but the one near 700 nm is hardly in the range of the human sensitivity (Figure 4).



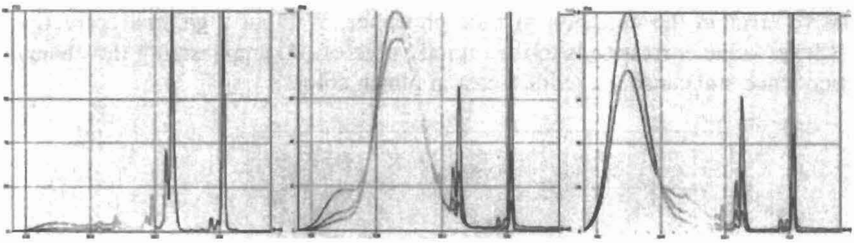
(a) (b)

Figure 4. CIE- Color-matching functions and RGB phosphors emission spectra(a). Intensity change in CIE-xy (b).

It is often said that monitors are additive and an ideal color systems compared with the subtractive color systems of the printing techniques. However some monitors are far from ideal. The monitor's color rendering and its ideality mainly depend on the the electronic beams that hit the RGB-phosphors. Unwanted and inexact beams that hit the neighboring phosphor also produce some emission of the unwanted phosphor. This directly affects the ICC profile ability to carry color information based only on the gamma values and the RGB phosphors CIEYXY color coordinates.

The monitor ideality for a color system may be tested with a image where each RGB channels values are set equally from light to dark (for example 64,128 and 255). Patches are measured with a spectrophotometer and the shape of the spectra with different tone values reveals possible channel dependencies.

The color coordinates clearly approach the neutral areas in the CIE-xy diagram. This due to the increasing relative changes across the spectrum with dark tones so that the emissions of the red phosphors also affect the emissions of green and blue phosphors. These emission peaks are clearly detectable in Figure 5.



R G B

Figure 5. RGB 255, 128 and 64 levels and their relative spectral distributions.

The spectra are relative and clearly show the relative changes in the visible range at the typical wavelengths of red phosphors. The other channels (G,B) dependency on red channel electronic beams is not so visible because they have no clear peaks in their emission spectra. Channel dependence can be explained by emission across visible light with two blue levels (255,128, Figure 6).

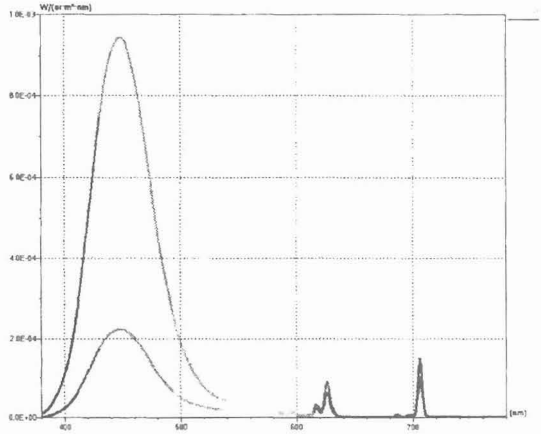


Figure 6. Blue phosphor emission with levels 255 and 128.

Although the emission of the blue phosphor clearly diminishes near the wavelength of 450 nm red phosphor maintains its emission levels causing a relative error in the emission of blue phosphor. Without a gamma correction, 128 level value corresponds to the digital value of 64, emphasizing the channel dependence and causing a reddish cast in bluish colors.

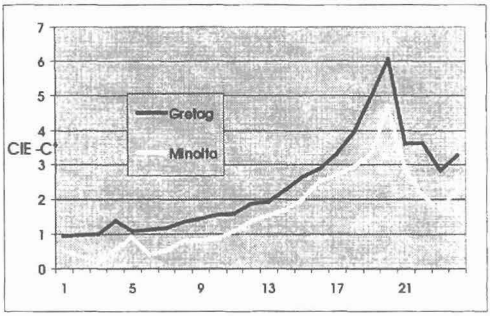


Figure 7. The monitor's gray balance in CIE-C* values.

The monitor's gray balance was measured with 24 gray steps.The spectrophotometer (Gretag) and the spectroradiometer (Minolta) show increasing chromaticity towards a reddish hue in the dark tones. This is due to red phosphors sensitivity to green and blue guns. The measurements made by the spectroradiometer produce more neutral results but the selected white point of D50 was also adjusted with the spectroradiometer. The possible use of incandescent lamps will enhance the effect. Strong channel dependence or a poor gray balance of the monitors will make the basic ICC profiles useless, especially without black point adaption with dark tones.

Monitor white selection

The monitor's poor channel independence also affects the RGB CIE-Yxy coordinates by white point adjustment or selection. The monitor's white selection affects the maximum level of luminance, as well as the gamma values. If the changes in the white point are small the effects are not significant.

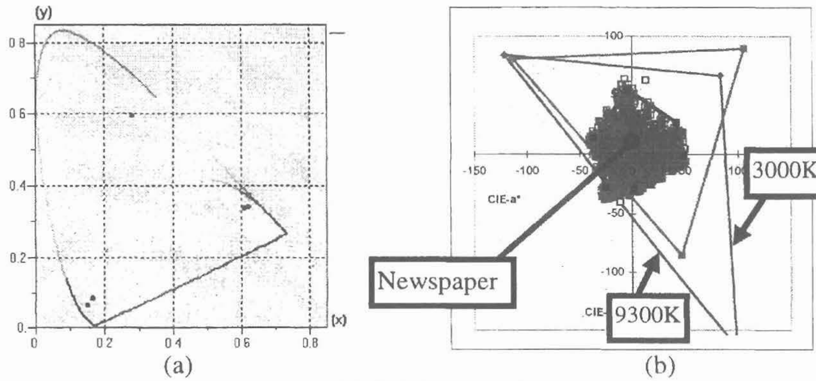


Figure 8. Remarkable changes (9300-3000) in monitor white adjustment cause clear changes in the RGB CIE-xy (a) and CIE-Lab values.

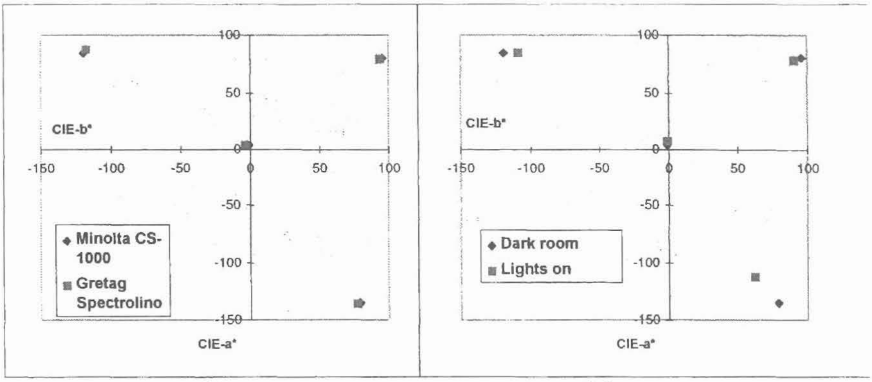
As Figure 8-b shows clear changes in the white point also change the color space. The white point of 9000K will spread the color space in the cyan area giving a better match for newspaper but the yellow part might squeeze too much for rotogravure simulation. However, the order of the calibration steps may have a clear effect on the right color definition of the ICC profiles.

Adjustment of brightness and contrast

As with the adjustment of the white point, the monitor gun's adjustment of brightness and contrast settings will also affect monitors ability to produce color. Brightness and contrast settings will affect gamma function and the dynamic range[6].

The ambient light affects on color and tone rendering

The ISO standards on viewing proofs and print define the levels of illuminance. The measuring instruments attached directly to the monitor surface seldom match directly with the levels of luminance reflecting from a paper or other substrate. The ambient light will also change the color values and especially the tone rendering. Color value will change remarkably if the incandescent lamps are used. To study the effect of ambient light measuring instruments consistency was first checked.



(a) (b)

Figure 9. The similarity of the spectrophotometer and the spectroradiometer (a) and the effect of the ambient light affect on CIE-LAB values in office room (b).

The measurement by the spectrophotometer (Gretag) and the spectroradiometer have a good CIE-C* and CIE-h match. The luminance values show a difference of 20 cd/m^2. The monitor's white point keeps the CIE-a*b* values well. Figure 10 reveals as an example the reason in the ambient light spectrum. Its peaks (almost equal emissions) are symmetrically near the D50 lights dominant wavelength which was also the monitor's white point.

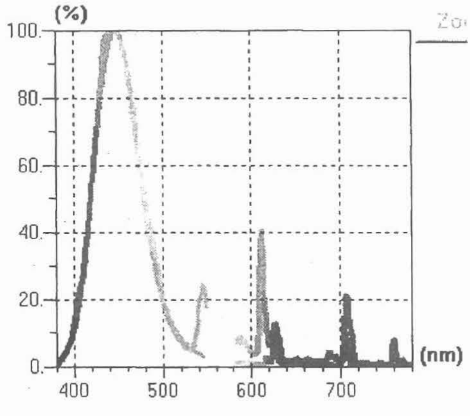


Figure 10. The ambient light affects blue phosphor.

Besides, ambient light does not have a strong effect on the color values in light tones because of the strongly competing emissions from the phosphors. Instead, the blue phosphor changes its CIE coordinates

ColourSync as a color prediction model

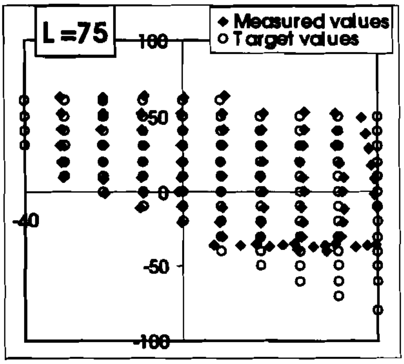
The monitor's ability to function as proofing equipment is studied by producing RGB triplets through ColorSync that represents the wanted CIELAB triplets. The color space is scanned in equal steps and the differences between the measured and the target values are compared. Only absolute colorimetric rendering intent is used.

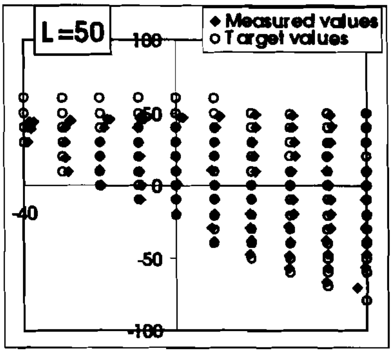
To study the effect of the ambient light, the displayed colors having also the reflections from the ambient light were measured with the spectroradiometer and the CIEXYZ color coordinates were used with the ICC profile. These profiles were compared with those made in the darkroom.

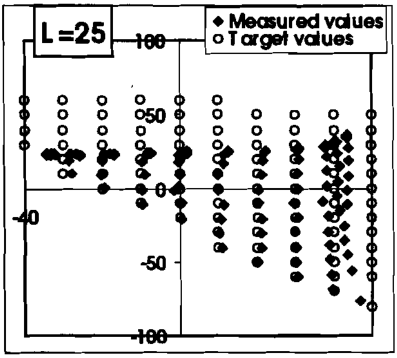
Experimenting with ColorSync and ICC profiles

The Generic CIELAB- ICC profile values were transformed with the monitor's ICC profile into display values. These measurements do not show the accuracy of the printing press profiles. The focus is on the monitor's color rendering performance with ColorSync 2.0.

Statistical values represents the target colors with less chromaticity than CIE-C* units of 40. Absolute color rendering intent was used without any color mapping and the limitations of the monitor gamut were not considered in the calculations.







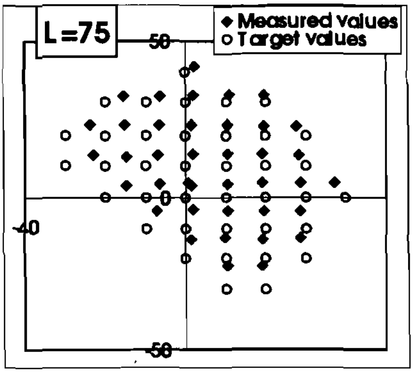
	CIE-L	75	50	25
deltaE	Ave	1,83	2,65	4,53
	Stdevp	0,17	0,20	2,25
	Min	1,52	2,25	3,11
	Max	2,25	3,06	15,55
deltaC*	Ave	0,83	0,55	2,28
	Stdevp	0,38	0,38	2,86
	Min	0,19	0,05	0,32
	Max	1,75	1,56	15,19

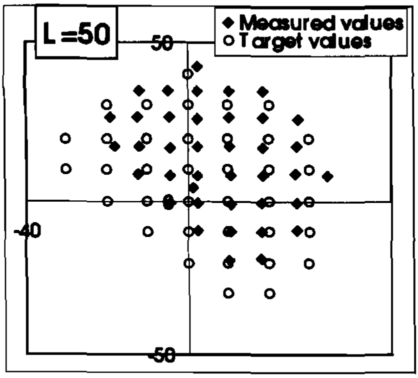
Figure 11. Monitor ICC- profile accuracy in a darkroom

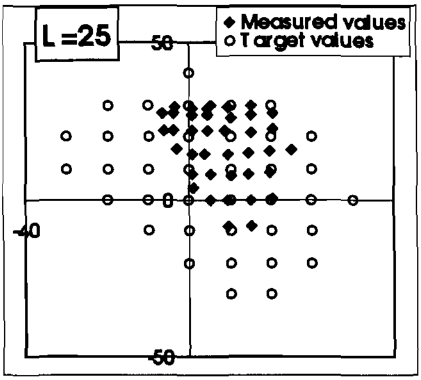
A good monitor with an updated ICC profile gives a good match for the required colors. If the monitor's white point is adjusted to the CIE-xy coordinates of D50, the match seems to be better than with default white points of the monitors (usually D50), even if the relative colorimetric rendering intent is used to compensate the different white points. Also the black point was measured but the basic profile file did not get the color values of the black point in the media black point tag.

In general there may be interoperation problems between different types of CMM modules and ICC profiles [5] with large look-up tables so that only the basic ICC- color monitor specifications are used in this experiment. For example in this study the LOGO/GRETAG ProfileMaker 2.2.7 did not transform the black point properly through its look-up tables and through CIELLAB encoding.

Monitor proofing in a room lighted with fluorescent and incandescent lamps







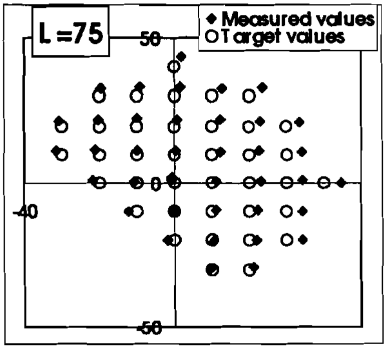
	CIE-L	75	50	25
deltaE	Ave	5,42	10,44	21,50
	Stdevp	1,35	1,87	4,09
	Min	3,15	6,57	14,09
	Max	7,97	14,93	30,18
deltaC*	Ave	5,15	8,65	15,86
	Stdevp	1,50	2,34	6,01
	Min	2,45	3,29	0,84
	Max	7,88	13,85	26,88

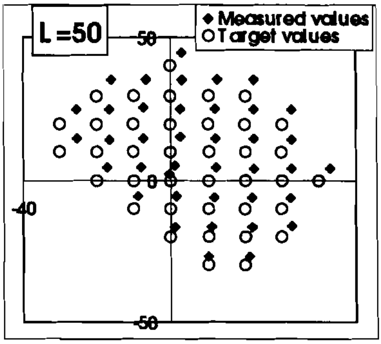
Figure 12. Absolute colorimetric rendering. ICC-profile

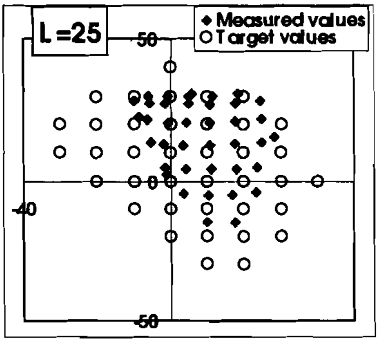
In this case, the basic "darkroom" monitor profile was used to transform the CIE-LAB target values into the display values. The light intensities were high, to demonstrate the strong effect on colors. The colors with a CIE-L value of 25 or less are mostly reflections from the light sources.

The selected lighting conditions could be regarded as the "worst" conditions and this experimental installation was exaggerating the normal lighting in office rooms. So the conditions might simulate more closely the bright lights at home. As Figure 12 shows the colors strongly shift to towards orange-red in all three CIE-L levels.

Monitor proofing in a lighted room with a profile that includes the ambient light







	CIE-L	75	50	25
deltaE	Ave	2,89	7,82	19,50
	Stdevp	1,16	1,31	2,87
	Min	0,32	4,94	14,55
	Max	5,09	9,74	28,63
deltaC*	Ave	2,49	5,25	2,32
	Stdevp	1,18	0,94	1,34
	Min	0,19	3,30	0,00
	Max	4,69	6,99	4,83

Figure 13. Absolute colorimetric rendering. The ICC profile includes the colors of the ambient light.

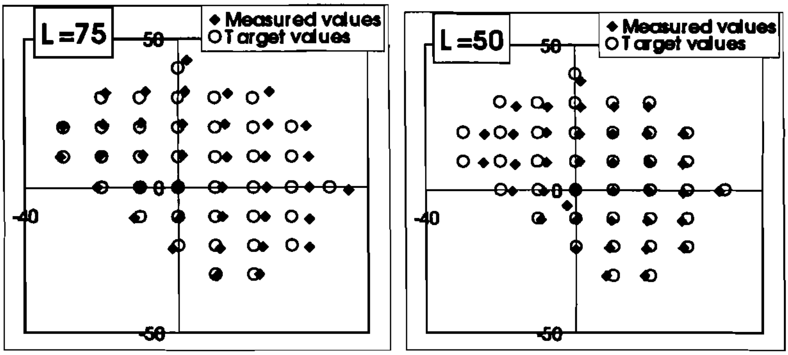
Figure 13 shows how the target values were transformed in a room where was a mixture of two lights (fluorescent and incandescent lamp). The monitor's color profile was defined with a spectroradiometer at a distant of 40 cm so that the ambient light had a free path to reflect from the monitor's glass surface towards the measuring instrument. The absolute rendering intent gave with a level of CIE-L=75 better results than the "darkroom" color profile while the measured colors at the CIE-L levels of 50 and 25 were badly distorted.

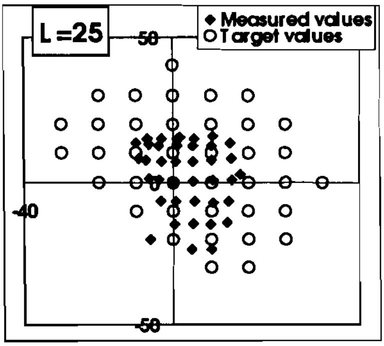
Monitor proofing in a lighted room, with a profile that includes the ambient light with grey/black point colorimetric matching

Here the measured color values were changed to match the D50 coordinates white point with a measured gray axis or a black point (media white). The transformation was made with the media white correction defined in the ICC specification:

$$X_r = (X_{D50} / X_{mw})$$
$$Y_r = (Y_{D50} / Y_{mw})$$
$$Z_r = (Z_{D50} / Z_{mw})$$

The media white or gray point was measured on the monitor where the target CIE- values were defined to be CIE L,0,0 with a white point of D50.





	CIE-L	75	50	25
deltaE	Ave	2,61	2,05	11,48
	Stdevp	1,26	1,32	5,57
	Min	0,00	0,02	0,01
	Max	4,97	5,90	24,34
deltaC*	Ave	2,32	1,82	11,47
	Stdevp	1,34	1,35	5,57
	Min	0,00	0,00	0,00
	Max	4,83	5,85	24,34

Figure 14. The absolute colorimetric rendering and black/gray point adoption at all three levels. The ICC profile colors include the ambient light.

The color values match the corrected gray axis notably better down to the level CIE-L=25 where an ambient light reflections from the monitor's surface glass clearly compete with the emission from the phosphors of the monitor. The color values approach the white point of the ambient light. In this case, the defined target values saturate and meet the color space gamut.

The monitor, ColorSync and the ICC- profile predicting printed documents with well defined print color profiles

The measurements of print quality have usually two key figures, i.e. the deviation from the target color value and the variation of the printed color. The monitor is usually very stable reproducing the colors compared to printing process. Only the luminance varies remarkably across the monitor's surface. The deviation of the color values is thus the interesting key figure of soft proofing. It shows the systematic color reproduction errors of the press.

Print deviations, normal or abnormal, has have reported from several research projects.[1,4]. There are also standards which define some tolerance values of the acceptable quality[3]. In table 2 are some examples of print deviation.

Table 2.

	Rotogravure	*Web offset*	*Newspaper*
Deviation ΔE	1-1,5	1,5-2,5	6-9

The newspaper color deviation values given in the table 2 were measured from 25 Finnish newspaper offset presses. In some newspapers, the average deviation was much larger approaching the value of 12 ΔE.

ISO 12647-3 standard gives for lithography newsprint deviation tolerances for the primary process color solids from 5 to 8 ΔE_{ab} units depending on the process color.

Considering the reported print deviations and the standards, the monitor's ability with ColorSync and ICC profiles to produce the required colors within the limits of its color gamut, the monitor is a very good tool in the darkroom. The dark chromatic colors of the rotogravure print are unattainable on most displays.

However newsprint can be viewed on a well calibrated monitor under normal office lighting conditions because the luminance of the newspaper's black point is considerably higher than a black points of the other printing techniques (Figure 3). Also the gamut of the monitor can easily attain most of the colors in newspaper print.

Conclusions

Displays and ColorSync with well defined and updated ICC profiles is a very good and fast proofing method, especially if no other proof is available. For example the same advertisement can be printed on the same day in several newspapers. Every press cannot have the hard proof matched for their printing presses. That is why they do not necessarily use proofing at all. These situations are more often reality because graphic arts production, which is converting from centralized to networked. The monitors can also compete with hard proofs of the newspaper, because their color and tone rendering capabilities are closer to newspaper's color and tone rendering than other printing techniques.

ICC profiles, which only define the RGB color coordinates with channel gamma values are not adequate if the monitor's color channels are not independent, or the ambient light must be accounted. In this case the look-up tables and the interpolation must be currently CMM specific to produce the best result.

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Appendix: List of the used equipment and software

Software:	**Hardware:**
Colorsync 2.6.1	Apple Power Macintosh G3
LabColor2.0.5d/ LOGO	DELL-monitor
LOGO Profile Editor 2.2.7	Minolta CS 1000-spectroradiometer
Apple ProfileEditor	Gretag Spectrolino spectrophotometer