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Effects Of Display Gamma And Illuminant On The Appearance Of Colours Viewed On Lcd Monitors

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Abstract

The CIECAM02 colour appearance model was developed to allow prediction of accurate colour appearance under various viewing conditions. In this study, a software module, based on mathematical transformations of the CIECAM02 model, was designed and implemented. Unlike the previous software modules, which were allowing use of only a limited choice of common standardized ICC display profiles, the developed module also allows the use of optimized profiles created by the user. This paper presents prediction of the appearance of test images with assigned different display profiles after changing illuminant. The two used optimized profiles, created by software characterization of specific LCD display, have a different display gamma value (1.8 and 2.2). It is observed that, after changing the initial CIE D50 to a higher colour temperature illuminant (D65), the colours of images will be shifted to the blue hues, and, in the case of illuminant temperature less than D50 (A and F11), to yellow hues. It is also observed that the intensity of colour shifts in the simulated images with associated profiles which have different gamma value will be significantly different, which implies that the ICC display profile and display gamma value have the great impact on the prediction of the accurate colour appearance under various viewing conditions.

Keywords:

ICC profile, gamma, CIECAM02 colour appearance model, viewing conditions

1. Introduction

The colour appearance models represent mathematical models which, through a series of transformations (a linear transformation from XYZ tristimulus values to cone responses, the chromatic adaptation transformation, transformation to opponent and achromatic responses etc.) calculate the colour values in order to predict the colour appearance across disparate viewing conditions, after the adaptation of the human visual system to changes. In graphic industry is currently used and widely accepted CIECAM02 model, defined by CIE organization (2002). Using CIECAM02, the following perceptual colour attributes can be calculated: the absolute color appearance attributes of brightness (Q), colorfulness (M) and hue (h) and the relative color appearance attributes of lightness (J), chroma (C), saturation (s), and, again, hue (h). Then, with the inverse transformation from perceptual attributes XYZ values are computed, taking into account the given final viewing conditions (Fairchild, 2005). The CIE Lab colour space can be considered a colour appearance model because it includes simple chromatic adaptation transforms and predictors of lightness, chroma and hue. However, the Lab colour space does not have the capability to include the effects of the background and surround in which the stimulus is observed, so it is not sufficient to predict the impact of viewing conditions. Therefore, there is a tendency to implement CIECAM02 model in the workflow of colour management systems (Fairchild 2005). In colour management system, profiles are used to describe the condition of some device and its capabilities in terms of colour reproduction. For graphic applications, profiles recommended by CIE, FOGRA and similar institutions or specially generated for a particular device by the manufacturer, are often used. The advantage of using these profiles is reflected in the possibility of their use for the class of the device and the specific work requirements. However, these profiles do not show the actual reproduction capabilities of device. Using optimized profiles in colour management systems (profiles generated intentionally for specific device) instead of standardized ones, involves a number of advantages, with the main advantage being the assur-

ance of maximum performance achievement of device with respect to the given parameters.

The optimized ICC display profiles are used when we want to completely accurately characterize a specific monitor, which is of great importance for a consistent soft proof (Sachs 2008).

Monitor calibration and profiling ensure that the white point of display, RGB primaries and gamma value are set correctly (Sachs 2008). The value of gamma, as one of the basic parameters that are defined during calibration of the monitor, has a great impact on the appearance of the colours. It describes non-linearity between the digital signal and the luminance values of colours on the display (the tone reproduction curve of signal). In case of the GOG model of calibration of CRT monitors, this non-linearity is defined as (CIE technical report 122-1996):

$$L = (AV + B)^\gamma \quad (1)$$

where L represents the normalized display luminance, v is the normalized input signal of red, green and blue channels, γ is the value which describes the non-linearity in the relationship (gamma), A and B are the values of gain and offset of the input signal, respectively. Unlike CRT monitors, which were originally non-linear display devices, the LCD displays have natural linearity in relationship between the input signal and the display luminance. However, manufacturers of LCD monitors intentionally build in circuitry that changes the display's natural linear light output characteristic into a non-linear characteristic in order to mimic the gamma of CRT displays (Schulte 2004). In the case of the LCD monitors, equation (1) is, due to production technology, simplified:

$$L = V^\gamma \quad (2)$$

Gamma value defined by equation (2) is the physical (original) gamma of monitors and for most monitors this value is 2.5. Adjusting LUT of graphic card original gamma can be customized to the desired value. Corrected gamma value is usually called a display gamma. In Windows operating systems, the display gamma of 2.2 is recommended, whereas in case of the Mac systems,

this value is slightly lower and amounts to 1.8. In accordance with (2), the value of gamma has the largest influence on the reproduction of middle tones, while the colours are generally perceived as darker with an increase in the gamma value (Poynton 1996).

Soltic and others (2004), based on mathematical calculations, showed that the change in the gamma value leads to changes in the perceptual attributes of colour defined by CIECAM02 model, using the matrix conversion from RGB to XYZ colour space of standardized sRGB profile.

Bodrogi et al. (2002) concluded that there are significant differences between the colours when using standardized sRGB tone reproduction curves of channels instead of actually measured curves. He and others (2008) have pointed to significant colour differences defined in the CIE Lab and CIECAM02 colour spaces as a result of changing the system gamma of LCD display.

Besides the viewing conditions, input parameters of CIECAM02 model are XYZ tristimulus values of image pixels, which are determined by ICC profile assigned to image, whereas the previous software were allowing use of only a limited choice of common standardized ICC display profiles. A software module was developed and implemented, which, in addition to standard, allows the use of optimized display profiles created by the user.

In this study is simulated the appearance of images with assigned optimized ICC display profiles which have different display gamma, after changing the initial CIE D50 illuminant to D65, F and A illuminants, based on the CIECAM02 model. It was assumed that the increase in illuminant temperature will lead to colour shifts to the blue hues and the decrease will cause the shifts of colour to yellow hues. It was also assumed that there will be the significant colour differences between the simulated images with associated profiles which have different gamma value. The RGB values of processed images are converted to the Lab values and the position of the colours in the images was observed and compared in the CIE Lab colour space. Methods, as well as presentation and discussion of results, are defined below.

2. Method

Before the beginning of testing, software calibration and characterization of specific LCD monitors used in this study (Samsung T220) was carried out. With software calibration (D50, 100 cd/m²), display gamma value is set to 1.8 in the case of the first ICC display profile, and to 2.2 in the case of another ICC profile.

The values of gamma 1.8 and 2.2 were selected on the basis of the recommended values for Windows and Mac operating systems, respectively.

In the case of both ICC profiles, matrix conversion from one colour space to another is used. In other words, one matrix describes the conversion of each colour that the monitor is able to display. Conversion matrix is represented in equation (3):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix} \begin{bmatrix} (R_{8bit} / 255)^\gamma \\ (G_{8bit} / 255)^\gamma \\ (B_{8bit} / 255)^\gamma \end{bmatrix} \quad (3)$$

where:

X, Y, Z – tristimulus pixel values

X_r, Y_r, Z_r - maximum tristimulus values R channel

X_g, Y_g, Z_g - maximum tristimulus values G channel

X_b, Y_b, Z_b - maximum tristimulus values B channel

R_{8bit}, G_{8bit}, B_{8bit} - digital 8-bit values for red, green and blue channel

γ - gamma.

Matrix elements of created ICC profiles are given in:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.5272 & 0.3060 & 0.1310 \\ 0.2766 & 0.6512 & 0.0722 \\ 0.0113 & 0.1114 & 0.7022 \end{bmatrix} \begin{bmatrix} (R_{8bit} / 255)^\gamma \\ (G_{8bit} / 255)^\gamma \\ (B_{8bit} / 255)^\gamma \end{bmatrix} \quad (4)$$

Characterization of the monitor, besides the conversion matrix, includes tone reproduction curves- gamma function of each channel (Burns, 2002).

After that, profiles are assigned to test images and images are processed using a software module based on the CIECAM02 model in order to

simulate the influence of different illuminants on appearance of test images. The CIE illuminants D65, D50, F11 and A are used as the most common illuminants in graphic industry. The soft proofs of the printed reproductions viewed under those illuminants can be obtained by converting the RGB profile of the simulated images to the ICC printer profile.

Accounting the ICC profile and initial viewing conditions settings selected by the user, the module converts digital RGB pixel values of the input image (on the pixel-by-pixel basis) into device-independent x, y, z tristimulus values, and then into the perceptual colour attributes, which are both device-independent and independent of the viewing conditions. After that, the module performs the inverse transformation back to RGB pixel values, using the final viewing conditions settings and colour space, also chosen by the user, and generates the final image preview. Parameters of surround are defined depending on the type of surround (average, dim and dark) (Fairchild 2005).

Algorithm of the software module is shown in scheme (1).

Module (plug-in filter) was developed for the software Adobe Photoshop and other compatible graphics software (Corel PhotoPaint, Jasc Paint Shop Pro, Macromedia Freehand and others), using open-source FilterMeister develop-

ment environment and compiler.

The elements of a graphical user interface module shown in Figure (1).

Filter settings are grouped in five frames:

- 1 RGB PROFILE PARAMETERS. Options for input and output profile (area) are: sRGB, AdobeRGB, ColorCheck and KAL_PROFIL. Choosing option KAL_PROFIL the filter will take as elements of the matrix conversion XYZ-RGB user settings entered through the scrollbars in this frame.
- 2 THE FORWARD TRANSFORMATION - the initial viewing conditions
- 3 THE INVERSE TRANSFORMATION- the final viewing conditions

User settings regarding the initial and final viewing conditions are:

- white point or CIE standard illumination (options: D65, D50, F11, A);
- surround (options: Average, Dim, Dark);
- relative luminance of the background Yb (range :0-100%, usually is taken 20%);
- adapting field luminance La (range: 000-300 [cd/m²], often 20% of the luminance of white)
- degree of adaptation D (range: 0 (no adaptation) - 1 (full adaptation) or auto adaptation)

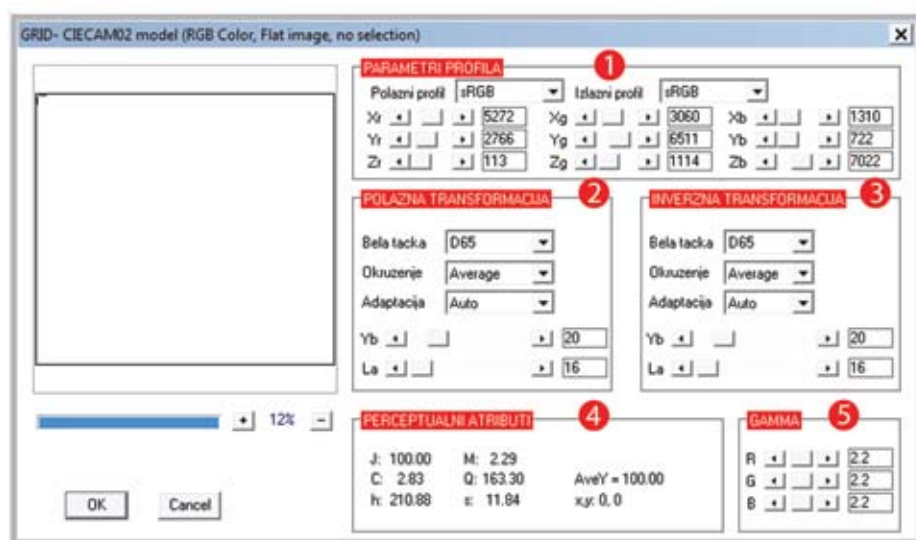


Figure 1: User interface of module (filter)

4 PERCEPTUAL ATTRIBUTES

For the selected pixel in the image, its x, y position coordinates as well as all 6 perceptual attributes CIECAM02 model can be seen.

5 GAMMA VALUES RGB CHANNELS SEPARATELY

In this paper, the GretagMacbeth SG test colour chart was used as a test image. The following values are taken as the initial viewing conditions:

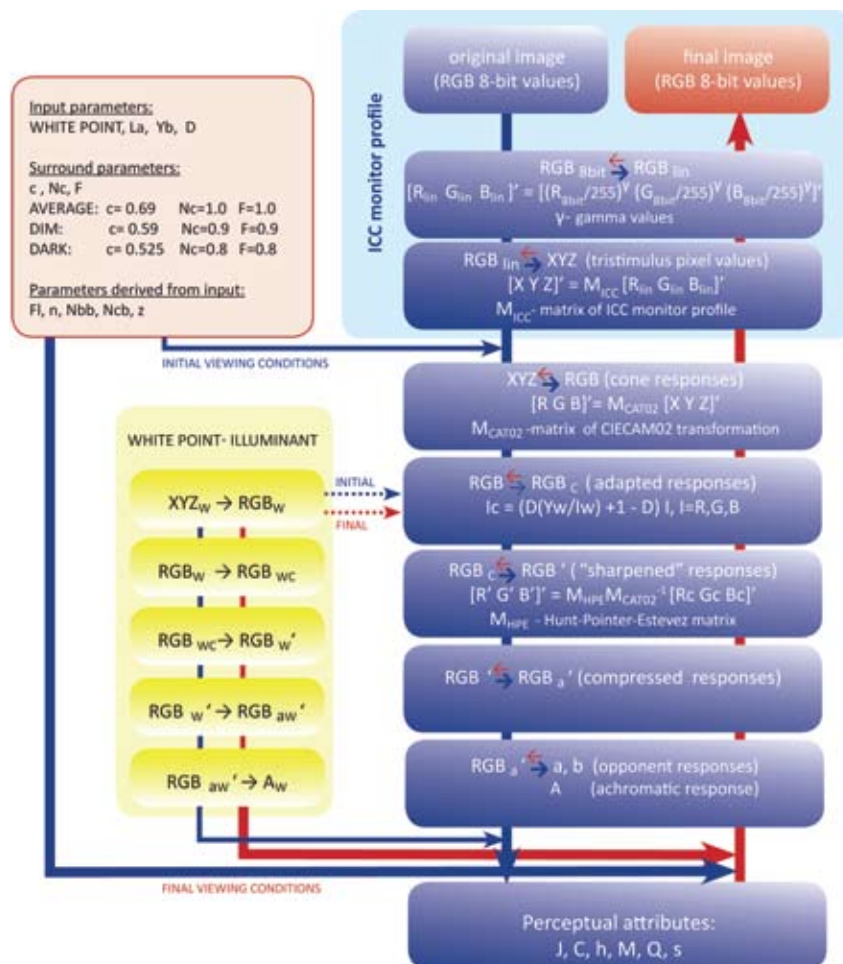
- White point: D50
- The type of surround: average
- The degree of adaptation: auto adaptation defined by CIECAM02 model
- Relative background luminance y_b: 20%
- adapting field luminance L_A: 20 (since the luminance of white point of monitor

is set during the calibration at 100 cd/m², for L_A has adopted a value of 20 cd/m²).

Test image processing was done by using a software module in Photoshop CS3, and then observed colour gamut of images in Lab space using software Chromix ColorThink.

3. Results

When the white point (illuminant) in forward transformation is different from the white point in inverse transformation, the software module performs a chromatic adaptation, based on CIECAM02 model. The appearance of the original images and the images after the transforma-



Scheme 1: Algorithm of software module (the blue flow is forward, and the red flow is inverse transformation of CIECAM02 model)

tions, as well as shifts in their colour gamut, are shown in the figures (2) and (3).

In the images after the transformations, it can be observed that the colours observed under the standard CIE illuminant with a higher temperature than the initial illuminant D50 (5000K) will be shifted to the blue hues, and, in the case of illuminant temperature less than D50 illuminant, to yellow hues. The same phenomenon can be observed in the figures (2e) and (3e), watching the colour gamut of simulated images with respect to the b axis of the Lab space. In figures (2) and (3) it can also be seen that during the changes of illuminant under which the image is observed (but with constant absolute luminance of illuminant), there are no changes in L (lightness) colour coordinate.

In figure (4), a comparison between the ranges of color (gamut) of original images is shown, and in figures (5) a comparison of the colour

gamut of images after the transformations, with different display gamma values.

In figure (4), it can be observed that an increase in display gamma value causes reduction in the lightness (4a), and, in most cases, leads to a slight increase in saturation (4b).

In figure (5) colour range of images is shown only as a projection in the a-b plane, because changing the illuminant, with other viewing conditions remaining constant, leaves the lightness values of colours unchanged. It can be observed that with a reduction in the display gamma, colour shifts to the blue hues in cases of higher illuminant temperature than the initial (D50 - 5000K) are more emphasized (5a). Analogous to this, with a reduction in the display gamma, colours will be more significantly shifted to yellow hues in the cases when the illuminant temperature is lower than the initial (5b) (5c).



Figure 2: a) Original image with assigned profile with gamma value of 1.8 (D50 - 5000K) Simulated images after changing illuminant to b) D65-6500K, c) F11-4000K d) A-2856K. e) Colour gamut of initial and simulated images shown in the CIE Lab space (2a: cyan, 2b: blue, 2c: yellow, 2d: red)

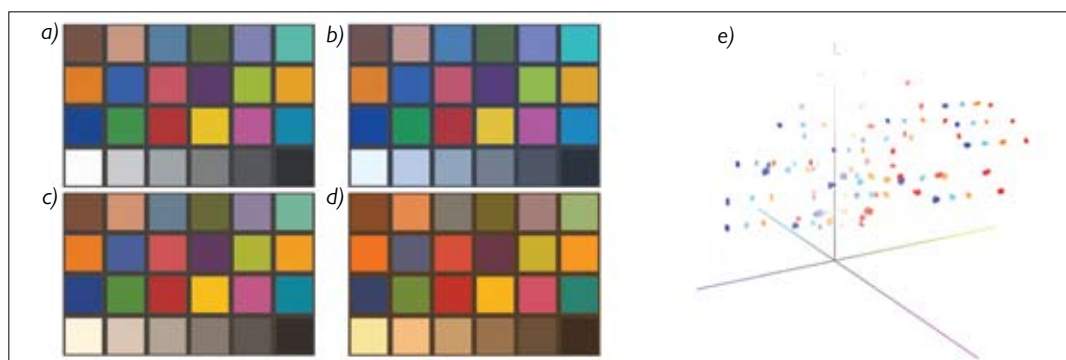


Figure 3: a) Original image with assigned profile with gamma value of 2.2 (D50 - 5000K) Simulated images after changing illuminant to b) D65-6500K, c) F11-4000K d) A-2856K. e) Colour gamut of initial and simulated images shown in the CIE Lab space (3a: cyan, 3b: blue, 3c: yellow, 3d: red)

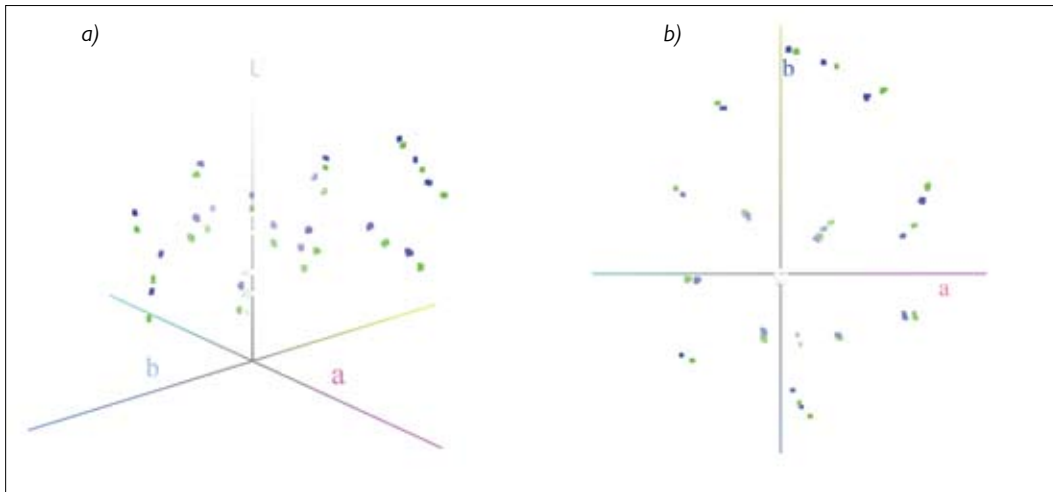


Figure 4: The colour gamut of original images in the CIE Lab space: a) 3D view b) projection in the a-b plane
Gamma value of 1.8 is shown in blue, and 2.2 in green.

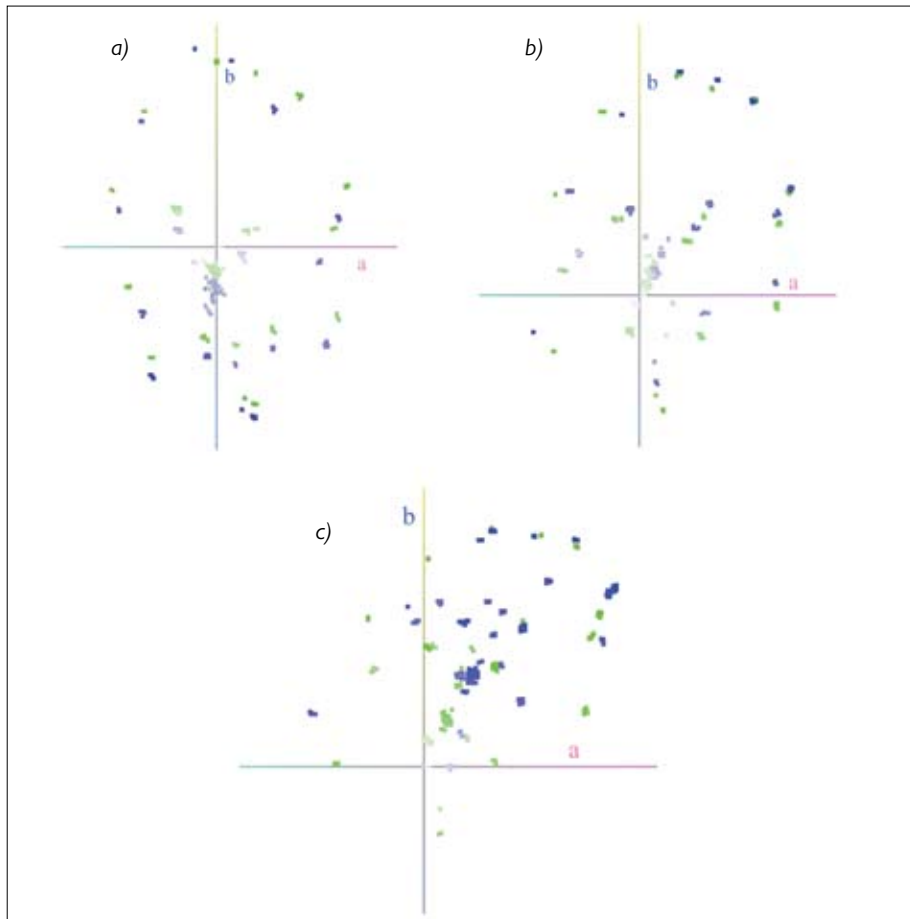


Figure 5: The colour gamut of original images in the Lab space (projection in the ab plane) after changing illuminant-white point from D50: a) D65-6500K, b) F11-4000K c) A-2856K. Gamma value of 1.8 is shown in blue, and 2.2 in green.

4. Discussion

In *figure (5)*, which represents the correlation between the colour gamut of original images in the CIE Lab space, it can be observed that increased gamma value leads to decreased lightness of colours. According to equation (2), a reduction in lightness is the most noticeable in the middle tones of images. The increased value of the gamma, under constant viewing conditions, generally leads to increased saturation. Since the saturation value is obtained with non-linear transformations of R, G and B original values, the impact of gamma on the saturation of colours cannot be uniquely described by mathematical correlation. In *Figure (6)*, it can be observed that changing the illuminant temperature has a greater impact on colour images with lower display gamma value in the following way: if illuminant temperature decreases, colours will be significantly shifted toward the yellow hues (positive end of b axis) and with increasing illuminant temperature, colours will be more significantly shifted towards blue hues (negative end of b axis) than the colours of images with higher gamma values. The reason for this phenomenon can be explained by the RGB values of pixels getting higher XYZ values with an increase in gamma values. It can be observed that the increasing difference between the temperatures of initial and final illuminants increases the final colour difference between images with different display gamma.

5. Conclusion

It is necessary for colour management systems, in order to enable good visual match between the printed reproduction and display soft proof, to take into account the conditions in which the image is observed. Using the developed graphic software module based on the CIECAM02 colour appearance model, the simulation of image appearance after changing illuminant or some other viewing condition (the luminance level, the type of surround etc.) was done. These simulated images with assigned RGB display profile can be converted to

the printer profile for the purpose of soft proofing of the printed reproductions viewed under specific illuminant. Assuming that the colours will get more accurate appearance, in this paper optimized ICC display profiles were used, rather than the standardized ones. It was shown that the display gamma plays an important role in the perception of the colours on the LCD display. After performing chromatic adaptation (changing illuminant) on the images with assigned different display profiles, significantly different prediction results are obtained. The larger difference between the initial and final illuminant caused the larger colour differences between the simulated images.

The consistent and accurate appearance of colours viewed on LCD monitors assures that, after converting the profile of processed image to the ICC printer profile, the consistent and accurate soft proof of the printed reproductions viewed under specific viewing conditions is also obtained.

Therefore, the precise characterization of the monitor and the right choice of the display gamma value are of great importance for the prediction of the impact of changing illuminants on the appearance of the reproductions.

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