# A comparison between a CRT and a LCD monitors colors rendering

TOADERE FLORIN, NIKOS E. MASTORAKIS
INCDTIM Cluj Napoca
Str. Donath, nr. 65-103,
Cluj Napoca, 400293, ROMANIA
Florin.Toadere@bel.utcluj.ro

WSEAS Research Department
Agiou Ioannou Theologou 17-23
Zografou, 15773, Athens, GREECE
mastor@wseas.org

*Abstract:* - The motivation behind this paper is to study how different TV technologies work and to compare the colors that are rendered by the monitors. We analyze two different situations: a CRT monitor and a LCD monitor. Using the monitors' spectral power distributions, we propose a six steps spectral image processing algorithm which converts the spectral image in to the XYZ standard and then in to the RGB standard. Finally we color balance the RGB image in order to eliminate the monitors render colors hues. On the monitors displays we expect to see the same colors text image.

*Key-Words:* - spectral image, CRT and LCD monitors, monitors spectral power distribution

## 1 Introduction

In recent years multimedia technologies gained a lot of popularity using TV and monitors displays. This fact pushes the afferent technologies to the highest technical levels. The most important characteristic of a display is the colors rendering. A display device is an output device for presentation of information for visual and auditive perception, which was transmitted in various forms. When the input information is supplied as an electrical signal, the display is called electronic display [10]. A monitor or display is a piece of electrical equipment which displays images generated by devices such as computers, without producing a permanent record. The monitor comprises the display device, circuitry, and an enclosure. The display device in modern monitors is typically a thin film transistor liquid crystal display (TFT-LCD), while older monitors use a cathode ray tube (CRT). More general the display technologies can be characterized as: emissive (CRT, gas plasma) and Transsmitive (Liquid Crystal Display and Liquid Crystal on Silicon) [4].

In this paper our goal is to analyze from each category of display technology a representative display and to make a comparison between monitors' colors rendering possibilities. We analyze the CRT and the LCD monitors. In order to do that we use an illumination algorithm in which we use as input data the displays' spectral power distributions [4]. Function of monitor spectral distribution, for the color checker input text image [8], we obtain the brut monitor colors rendering for each monitor. In order to obtain the final monitor renders image we make the color balance. We expect to see on each monitor the same input color image without any color differences. From the display exterior, using the monitor's buttons, we can adjust the saturation, the brightening and the contrast of the colored text image.

## 2 The monitors colors rendering

Color vision is the capacity of an organism or machine to distinguish objects based on the wavelengths of the light they reflect or emit. Color derives from the spectrum of light (in our case the display light emission) interacting in the eye with the spectral sensitivities of the light receptors. The nervous system derives color by comparing the responses to light from the three types of cone photoreceptors in the eye L, M, S (long, medium and short) equivalent to R, G, B (red, green and blue) colors [2,4,6,7]. Reflected color can be measured using a reflectometer, which takes measurements in the visible region of a given color sample. If the custom of taking readings at 3.7 nanometer increments is followed, the visible light range of 400-700nm will yield 81 readings [8]. These readings are typically used to draw the sample's spectral reflectance curve. The color checker spectral image is defined as a 496X256X81. In order to render colors on a display we use an algorithm that convert the spectral image in to XYZ standard, and then in to the RGB standard in function of each monitor spectral power distribution [9]. Each monitor has a different spectral power distribution so we expect to have on each display the same image with different colors hues. Finally we make the white balance in order to have a realistic image from the colors hues perception. The white balance is the process of removing unrealistic color casts, so that objects which appear white in person view are rendered white on the display image.

Human vision is sensitive to visible light, that part of the electromagnetic spectrum with wavelengths from about 400 to 700 nm. Complementary displays render colored images in the visible wavelength band, in order to be perceived by human eyes. In our analysis color rendering means the ability of display or monitor to show true colors as they are seen outdoors in sunlight (or indoor under different bulbs illumination) by normal human eyes.

Our system consists of a spectral image [8] which is used as text image (the color checker image), and the CRT and the LCD monitors which render the text image.

We see the color checker text image on the monitors' screens. The monitors have different spectral power distributions [4] and in function of this we see the text image with different hues. In order to eliminate the image colors hues we color balance the image.

## 2.1 The spectral image processing algorithm

In this paper we use a spectral image under the Spectral Binary File Format (.spb). This format has the following characteristics: file identifier is a 3 letter string SPB (Spectral Binary file) located at the beginning of the file. Image dimensions and wavelength values are stored in file header. Dimensions ($x$, $y$ and n) are stored in uint32 format and wavelength values in foat32 format. Spectral image values are reflectance values stored as float32. Spectral image values are scaled between 0 and 1, where 1 describes maximum reflectance. Image data is written to the file in column order and values are stored in little endian form [8].

If we perceive light that is reflected from a surface, instead of light that is directly emitted from a light source, our eyes receive the result of the scalar product of reflectance and radiance spectrum. In continuous case human eye response is:

$$c_i = \int_{\lambda \min}^{\lambda \max} S_i(\lambda) r(\lambda) l(\lambda) d\lambda \qquad i = S, L, M \qquad (1)$$

were:

$S_i(\lambda)$ is the function of sensitivity of the $i$-th type of cones,

$r(\lambda)$ is the fraction of the reflected illuminant energy,

$l(\lambda)$ is the spectral distribution of light,

$L$, $M$, and $S$ are the responses of the long, medium, and short cones of the eye [2,4,7,9].

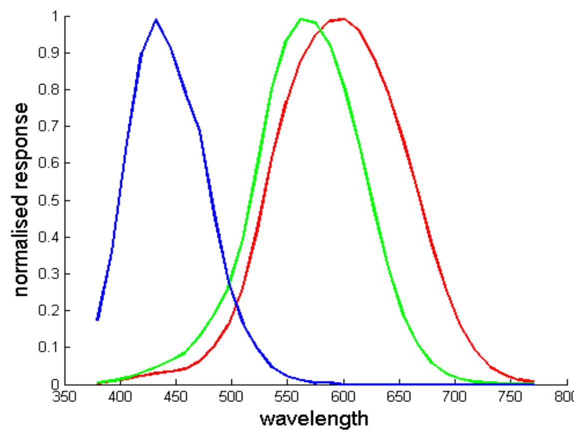

Figure 1. Normalized L, M, S cones

In 1931 *CIE* decided to propose a particular set of color matching functions as a standard. The color-matching function is defined to match the eye's sensitivity to brightness. X, Y and Z represent the weights of the respective color matching functions needed to approximate a particular spectrum.

$$X = k\sum_{\lambda} x(\lambda) f(\lambda)\Delta\lambda$$
$$Y = k\sum_{\lambda} y(\lambda) f(\lambda)\Delta\lambda \qquad (2)$$
$$Z = k\sum_{\lambda} z(\lambda) f(\lambda)\Delta\lambda$$

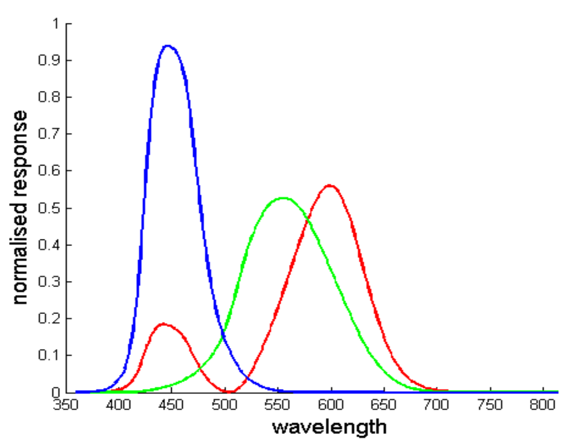

Figure 2. CIE 1931 XYZ primari stimuli

were $k$ is the normalization factor.
The matrix formulation is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 0.412 & 0.357 & 0.180 \\ 0.212 & 0.715 & 0.072 \\ 0.01 & 0.11 & 0.95 \end{bmatrix} \cdot \begin{bmatrix} r \\ g \\ b \end{bmatrix}. \quad (3)$$

The ITU-R BT.709 standard specifically describes the encoding transfer function for a video camera that when is viewed on a standard monitor will produce excellent image quality. The implicit target of this encoding is a standard video monitor whose transfer function or CRT gamma is not explicitly delineated. Instead a typical monitor setup is assumed. This recommendation specifies the encoding of real world scene tristimulus values into a standard monitor RGB color space assuming a dark viewing condition.

A common choice of primaries for a display device is the recommended standard 709 RGB primaries:

$$M_{709} = \begin{bmatrix} 0.640 & 0.330 & 0.030 \\ 0.300 & 0.600 & 0.100 \\ 0.150 & 0.060 & 0.790 \end{bmatrix}. \quad (4)$$

A white point is a set of tristimulus values or chromatic coordinates that serve to define the color white in image capture, encoding or reproduction. A commonly used white point is $D_{65}$ white point:

$$x_{D65}=0{,}3127;\ y_{D65}=0{,}3290;\ z_{D65}=0{,}3582. \quad (5)$$

The perceived brightness of a digital image render by a display is dependent of the display spectral power distribution. This affects the intensity distribution and interrelationship of contrast between light and dark regions in the specimen. Instead, the input value is effectively raised to an exponent called gamma. Gamma is the exponent on the input of the monitor that distorts it to make it darker. Since the input is normalized to be between 0 and 1, a positive exponent will make the output lower. The NTSC standard specifies a gamma of 2.2. By definition [3, 4, 5, 7] gamma is a nonlinear operation used to code and decode luminance or tristimulus values in video or image systems. Gamma correction is, in the simplest cases, defined by the following power law expression:

$$V_{out} = V_{in}^{\ \gamma} \quad (6)$$

At decompression the gamma values for NTSC standard is 0.45.

Luminance is a measure of radiant light energy that is based upon the non-linear human visual response (logarithmic) to light. This is because the human eye easily responds to specimens having low-amplitude, dim features in the same view field with bright highlights, but linear imaging devices are incapable of correctly reproducing the differences in luminance (and extremes in dynamic range) generated by these specimens. Exponential functions more closely match the logarithmic response of the human eye.

### 2.1.1 The colors rendering algorithm

In conformity with equation (1:6) we have the next spectral image processing algorithm:

1. Load the data into Matlab (spectral image and the monitors' spectral power distribution)
2. For each monitor's spectral power distribution, we compute the human eye color response using equation 1.
3. We compute the tristimulus values in XYZ for each pixel by applying the color matching functions CIE 1931
4. We compute the transformation matrix M to convert from XYZ coordinates to the 709 RGB primaries with a D65 white point
5. We convert from the XYZ standard into the RGB standard
6. The gamma correction

## 2.2 The colors balancing

Color balancing belongs to a class of digital image enhancement algorithms that are useful for correcting color casts in captured images. In our cases, unusual overall color casts (or uniform discolorations) typically result from different monitors' spectral power distribution. In our algorithm color balance adjustment is often necessary in order to produce acceptable color quality in digital images. The human eye is designed to readily adapt to changing illumination conditions in order to identify a white object as white even when the surrounding intensity and color temperature fluctuate. In contrast, monitors displays require careful scrutiny and adjustment of the red, green, and blue signal amplitudes in order to produce similar results [2,3,4].

The process of color balancing includes trying to determine what the illuminant of a particular scene (display) is and then we adjust the intensities of the red, green, and blue channel of the image in order to recover the original color characteristics of the scene. Since for most images, we can not accurately determine the scene illuminant, we considered a Mean and Standard Deviation algorithm [4, 9]. We noticed that many of the images seemed to be lacking in contrast, making them appear hazy. They also appeared to be quite dark in color, an indication of low mean channel values. Therefore, in addition

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to adjusting the standard deviation values we adjusted the mean of each channel as well. To compensate for these shortcomings in the original image, we adjust the mean of each channel to be 0.5, and we also set the standard deviation of each to be roughly 0.27 (or 70 on a 256 value scale).

## 3 The display overview

Image rendering electronic projective displays can be divided into emissive and transsmitive types. Emissive displays are those in which the image-forming element also serves as the source of light, while transsmitive displays modulate some aspect of an extrinsic illumination source. There are currently a large number of display technologies for rendering electronic images, the CRT (cathode ray tube) is the dominant emissive technology while the LCD (liquid crystal display) is the nowadays pervasive transsmitive technology [4,5,7].

In our paper each display is characterized by its own spectral power distribution. The spectral power distribution of a display represents the power radiated by the screen at the various wavelengths of the visible spectrum. In order to see how the monitors render colored text image, we use the monitors' spectrums as input data in our spectral image processing algorithm. The spectral power distribution of each of the individual channel adds linearly when combinations of the color channels are turned on. We compared the SPD of the white channel at specific channel color values with the sum of the SPD of the individual R, G, and B channels at the same channel color values. The results in (Fig. 3-4) show that there is very little discrepancy between the SPD of combinations of different channel color values to the corresponding sum of SPD of the individual color values.

### 3.1 The CRT monitor's operating principle

In a CRT monitor an electron beam hits a phosphor screen exciting it to emit a visible photon. Video input voltages are applied to each electron gun assembly, which includes control grids for modulating the beam current flowing from the cathodes as well as electrodes to accelerate, shape and focus the electron beams on the phosphor-coated faceplate. The electrons that pass through the shadow-mask apertures excite the R, G, and B phosphors. The phosphors absorb electrons which cause the light emission in a process called cathodoluminescence [5,7].

In Fig. 3 we see the SPD of the primary phosphor emissions in a CRT monitor. The red phosphor SPD has several discrete spikes. Such spikes are not commonly found in nature, and consequently the CRT emissions almost never match the spectral power distribution found in the original scene. The color match can only be arranged basing on the eye's inability to distinguish between different spectral power distributions (metamerism) [4,7].

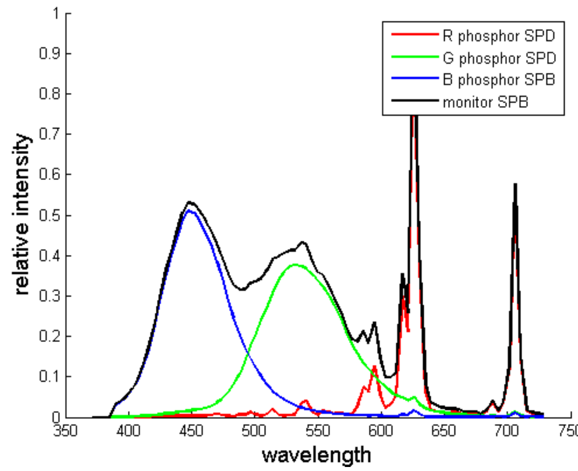


Fig. 3 the CRT monitor's spectral power distribution

### 3.2 The LCD monitor's operating principle

A thin film transistor liquid crystal display (TFT-LCD) is one type of active matrix LCD. It is composed of a backlight illumination source, diffuser, rear linear polarizer, glass sheets with transparent thin-film indium-tin-oxide electrodes and thin-film transistors, optically active layer of birefringent liquid crystal material, absorbing thin-film color selection filters, and a front polarizer. Farther information about LCD functionality can be found in [1].

The LCD backlight illumination is generate either by a hot-cathode or a cold-cathode fluorescent lamp. The fluorescent lamp has a high luminous efficiency and the ability to tailor the SPD of the lamp via the selection and mixture of individual phosphor components and their proportional contributions to the total phosphor blend. Tri-band phosphor mixtures are typically employed to improve color performance for these lamps. The final emission spectra are the weighted sum of the three phosphor emissions plus energy at the mercury emission lines (fluorescent lamp spectrum) [4,5,7].

In Fig. 4 we see the SPD of a LCD monitor. The three primaries SPD in a LCD display vary considerably. The spikes in the distributions are due to materials placed in the fluorescent backlights. The

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peaks of the backlight emissions are designed to fall at the centers of the pass bands of the thin-film color filters that are part of the LCD assembly [4,7].

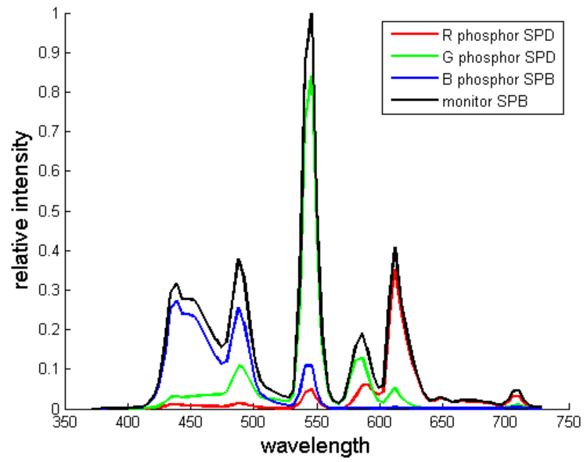


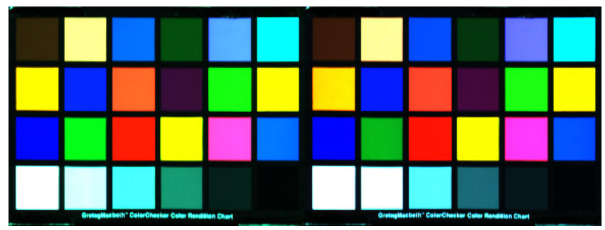

Fig. 4 the LCD monitor's spectral power distribution

## 4 The simulation results

Basing on the idea that the most important monitors' characteristic is colors rendering and assuming that we don't have problems related to resolution, we simulate the normal viewer colors perceptions on different monitors. In Fig. 3 and Fig. 4 we see the spectral power distribution afferent to CRT and LCD monitors. We see that the monitors' spectrums present big differences and we expect also the render image to present different hues. In order to eliminate the hues we make the white balance. In Fig. 5 we have the image renders by the CRT monitor. Due to the monitor's spectrum shape, we have little hues differences between monitor image (Fig. 5 a)) and the white balance image (Fig. 5 b)). In Fig. 6 we have the image renders by the LCD monitor. Due to the monitor's spectrum shape, we expect to have some green hue in the render text image (Fig. 6 a)). In Fig. 6 b) we have the corrected image for the LCD monitor. In Fig. 6 a) and Fig. 6 a) we see that the render monitors images are very different. But happily in the white balance corrected images (Fig. 6 b) and Fig. 6 b)) we see images with colors that seems to be the same. Also we notice that from the monitors' buttons we can change the brightness, luminosity and contrast, independent of our algorithm and function of the viewer needs.

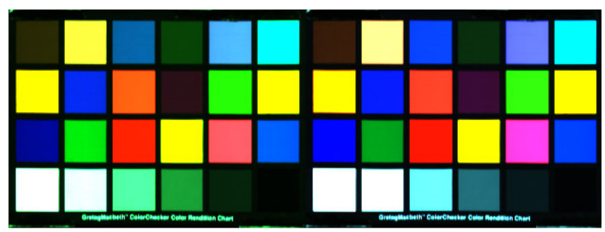
## Conclusions

In this paper we simulate the functionality of two different monitors from the colors rendering process point of view. Comparing the final results in Fig. 5 b) and Fig. 6 b) we see that the text image seems to have the same colors on each monitor. Because the monitors present constructive and functional differences, if someone wants to buy a display device, first is recommended to read carefully the display characteristics which are represented in a device profile file. The CRT monitors represent an old technology; the LCD monitors are the nowadays technologies.



a b

Fig. 5 a) the CRT monitor's colors rendering, b) the CRT monitor's white balance



a b

Fig. 6 a) the LCD monitor's colors rendering, b) the LCD monitor's white balance

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