A study about illumination and colors vision

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Abstract. In this paper we propose a software algorithm which can simulate the human eyes colors view. We present a spectral image processing algorithm, in which we use the color checker spectral image, the human eyes cones spectral sensitivity and the spectral power distribution for light sources. We use three spectrums of real lamps, made by EG&G PerkinElmer: sunlight 5500K, xenon flash and xenon CW, and three CIE light standard sources: D65, CIE A and F7. In order to validate the functionality of the algorithm we simulate the color checker picture hues difference, under different illuminations generate with the light spectrums presented in this paper.

1. Introduction

Human vision is sensitive to visible light, that part of the electromagnetic spectrum with wavelengths from about 400 to 700 nm. The illumination determines the amount of light that covers a surface. Color helps in the perception of the beauty of the digital image. The perceived color of the surface is determined not only by the color of the surface but also by the color of the light. Therefore, the type of lamp in the light fixture can significantly impact the perception of the color of the object. This effect should be taken into account when we see images on the computer screen. The perception of the object's shape differs with the light distribution on its surface and with the configuration of the resulting shadows. The direction of the light beam can easily affect the perception of the object's shape [1-4].

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 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 [8]. 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 [9]. These readings are typically used to draw the sample's spectral reflectance curve.

In order to see the image colors under different illuminations, we use a spectral image processing algorithm, which allow us to combine the spectral image with the cones sensibilities and the light sources spectral power distributions. We illuminate the color checker image with three EG&G PerkinElmer lamps and three CIE standards. Also we need to make compatibility between the monitor radiance and the human eyes perception. Using our algorithm we can chose any type of light sources.
2. 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 float32 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 [9].

If we perceive light that is reflected from a surface, instead of light that is directly emitted from a light source, our eyes receive result of the scalar product of reflectance and radiance spectrum [1-6]. In continuous case human eye response is:

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

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 [1-4].

The image obtained using equation 1 is not enough from the monitor colors possibilities of representation. In order to remediate this deficiency we have to make compatibility between monitor possibility of colors generation and how the human eyes cones perceive the colors radiance. We need to specify how the displayed image affects the cone photoreceptors [4-8]. To make this estimate we need to know: the effect that each display primary has on your cones and the relationship between the frame-buffer values and the intensity of the display primaries (gamma correction).

![Figure 1.](image)

Figure 1. a) L, M, S cones spectral response, b) a CRT monitor spectral response, c) inverse gamma function.

To compute the effect of the display primaries on the cones, we need to know the spectral power distribution of the display; a CRT (cathode ray tube) monitor (figure 1b), and the relative absorptions of the human cones (figure 1a). Having this data, we can compute the 3x3 transformation [4] that maps the linear intensity of the display R, G, B signals into the cone absorptions L, M, S (equation 2).

$$\begin{bmatrix}
14.0253 & -13.5154 & 0.7385 \\
-4.1468 & 10.1490 & -1.3618 \\
-0.1753 & -0.5663 & 7.3776 \\
\end{bmatrix}$$
In addition, the characteristics of the display device (screen display) where the digital image is viewed also affect the intensity distribution and interrelationship of contrast between light and dark regions in the specimen. The effects are characterized by a variable known as gamma [8].

\[ V_{out} = V_{in}^\gamma \quad (3) \]

Phosphors of monitors do not react linearly with the intensity of the electron beam. For CRT display monitors and televisions, the luminance produced at the face of the display is a power function, which is proportional to the voltage applied to the faceplate grid raised to an exponential power. The numerical value of the exponent of this power function is known as gamma. By definition gamma is a nonlinear operation used to code and decode luminance or tristimulus values in video or image systems.

In conformity with the equations (1)-(3) we have the next algorithm steps:

1. Load the data into Matlab (spectral image, lamps spectrums and cones response)
2. For each lamp spectrum illumination, we compute the human eye color response using equation (1).
3. We make compatibility between monitor possibility of colors generation and how the human eyes cones perceive the colors radiance using equation (2).
4. We make gamma correction, to correct the monitor luminance using equation (3).

3. Simulation results

3.1. Illumination simulation

In this paper we use as spectral image the color checker picture and three light sources from EG&G PerkinElmer: sunlight 5500 K, xenon flash lamp and xenon CW. These lamps spectrums spread in UV an IR but in our simulation we focus our attention on visible light between 380 and 780 nm, because the spectral image is defined only on visible range. The lamps spectral powers distributions are represented in figure 2b and further information can be found in [8, 10]. Also we simulate the illumination using the CIE standards: CIE A, D65 and F7 (figure 2a) [2, 7].

In order to present the functionality of the spectral image processing algorithm, we simulate the original color checker image illuminated with EG&G PerkinElmer lamps spectrums. In figure 3a we have the color checker original image. Because the lamps spectrums cover the entire visible spectrum and have little differences in shape (figure 2b), we expect that the illuminations simulations to have little differences. In figures 3b-d, we present the simulations make under the sunlight 5500 K illumination, xenon flash illumination and xenon CW illumination. On the other hand we have the
light sources spectrums standardized by CIE. We use three CIE standards: CIE A, D65 and F7. The CIE A standard represents a classical incandescent bulb, the D65 standard represents the midday sky without clouds and F7 represents a fluorescent source. Those light sources spectrums (figure 2a) are very different and we expect that the illumination effect (colors hues) to be very different (figure 4).

![Figure 3](image3.png)

**Figure 3.** the original color checker image, b) sunlight 5500 K illumination c) xenon flash illumination, d) xenon CW illumination.

![Figure 4](image4.png)

**Figure 4.** a) CIE A illumination, b) D65 illumination, c) F7 illumination.

### 4. Conclusion
As we can see from day by day experience the light sources and lamps have different colors hues, in function of the spectrums they cover. In this paper we image simulated the color checker characteristics (colors hues) under different light sources illumination. We simulate the illumination with three EG&G PerkinElmer lamps and we see that those lamps try to copy the sun light at 5500K. From figure 3 we see that the illuminated images have little colors hues differences. In figure 4 we simulated the color checker picture illuminated with CIE standards and we see that those standards effects are very different. In general our algorithm supports as input data any visible spectrums and works in real time.

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