A study about daylight perception by the human eye

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Abstract: - The goal of this paper is to analyze the daylight perception by the human eye and their adaptation to illumination. In order to do that we compute the spectral power distributions of the daylight, in function of these the color changes across the daylight. We simulate the perception of the daylight: in the sunset sky, the noon sunlight, the daylight etc. When the level of illumination is too high the iris makes prompt, momentary adjustments to changes in light intensity within the same light environment. Also, as measure of protection, the eye can be masked by windows or sun glasses.

Key-Words: color vision, spectral images, daylight spectral power distributions.

1 Introduction

Human vision is sensitive to visible light, that part of the electromagnetic spectrum with wavelengths from about 400 to 700 nm. Light can be understood as the aspect of radiant energy which an observer perceives through visual sensation, but also as a physical phenomenon. The visual system is the detector that transforms radiant power into luminous sensation. The imaging process accounts for the spatial light distribution on the retina by the optical eye media (cornea, pupil, lens, vitreous, etc.). The illumination determines the amount of light that covers a surface [1-3].

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 daylight color temperature 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.

Radiation from the sun that does get through the atmosphere and is visible to our eyes can be described in three ways: sunlight, skylight and daylight.

• Sunlight is light coming directly from the sun; the image of a shaft of sunlight into a darkened room.
• Skylight refers to the blue light of the sky as viewed from a location in complete shade, for example the light entering through a north facing window.
• Daylight is the combined light of sun and sky, for example as reflected from an unshaded sheet of white paper illuminated outdoors. Significant color shifts occur in daylight, depending on geography, season and time of day, but it is unchanged by scattered clouds or overcast: these only dim the light and diffuse it.

2 The color vision

Color is the attribute of visual perception consisting of any combination of chromatic and achromatic content. Perceived color depends on the spectral distribution of the color stimulus, on the size, shape, structure and surround of the stimulus area, on the state of adaptation of the observer's visual system, and on the observer's experience of the prevailing and similar situations of observation.

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 [1-7]. 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. These readings are typically used to draw the sample's spectral reflectance curve. The test spectral image [8] 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.

The light source has its own spectral power distribution. The spectral power distribution of a light is the function that defines the power in the light at each wavelength. The light from the source is either absorbed by the surface or reflected. The fraction of the light reflected by the surface defines the surface reflectance function. The surface reflectance function measures the proportion of light scattered from a surface at each wavelength. We can calculate the light reflected towards the eye by multiplying the spectral power distribution and the surface reflectance in order to obtain the colors signal. The colors signal is absorbed by the three cones from the eye and then it is send to nervous system in the brain vision area, where appear the sensation of colors perception. The light spectral power distribution satisfies the principle of superposition. For example the spectral power distribution of two lights mixture, will be the sum of the two separate spectral power distributions. This concept can be extended to the reflected light and the light propagation [1-3].

2.1 The spectral power distributions of the light

CIE illuminants D, which were intended to represent various phases of daylight, are specified by the following formulas. The relative spectral power distribution, $S_D(\lambda)$, of a CIE daylight illuminant is defined by

$$S_D(\lambda)=S_0(\lambda)+M_1S_1(\lambda)+M_2S_2(\lambda) \qquad (1)$$

where $S_0(\lambda)$, $S_1(\lambda)$, and $S_2(\lambda)$ are the mean and the most important "eigenvectors" of a large set of measured daylight distributions [1, 7].

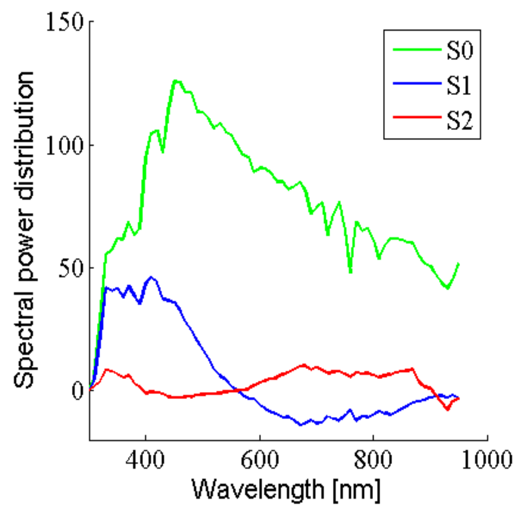

Fig.1 The spectral power distributions of the CIE daylight vectors $S_0(\lambda)$, $S_1(\lambda)$, and $S_2(\lambda)$

Figure 1 shows the spectral power distribution of the three CIE daylight vectors. M_1 and M_2 are scalar multipliers that are related to the chromaticity coordinates (x_D, y_D) of the illuminant by the following functions [7]

$$M_1=\frac{-1.3515-1.7703x_D+5.9114y_D}{0.0241+0.2562x_D-0.7341y_D}, \qquad (2)$$

$$M_2=\frac{0.300-31.4424x_D+30.0717y_D}{0.0241+0.2562x_D-0.7341y_D}. \qquad (3)$$

The chromaticity coordinates y_D is computed from x_D by

$$y_D=-3.000x_D^2+2.870x_D-0.275 \qquad (4)$$

which defines the "CIE daylight locus" in the CIE 1931 chromaticity diagram.

For correlated color temperature T_c, between 4000 K to 7000 K

$$x_D = -4.6070\frac{10^9}{T_c^{\,3}} + 2.9678\frac{10^6}{T_c^{\,2}} + 0.9911\frac{10^3}{T_c} + 0.244063 \quad (5)$$

For correlated color temperature T_c between 7000 K to 25000 K

$$x_D = -2.0064\frac{10^9}{T_c^{\,3}} + 1.9081\frac{10^6}{T_c^{\,2}} + 0.24748\frac{10^3}{T_c} + 0.237040 \quad (6)$$

Figure 2 shows the spectral power distributions of the CIE daylight illuminant at several correlated color temperatures.

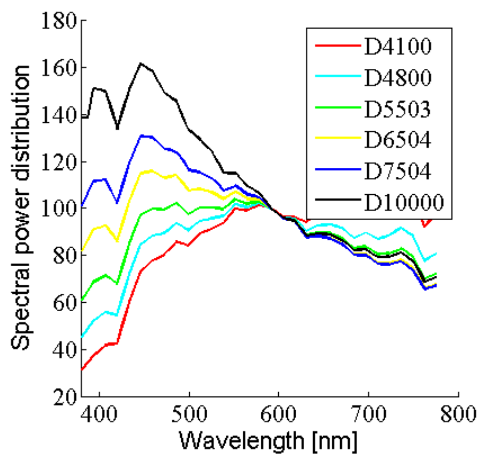

Fig. 2 The spectral power distributions of the CIE daylights

In order to reduce the number of illuminants used in colorimetry, the CIE recommends that D65 (T_c = 6504 K) be used as the preferred illuminant. When it is not convenient to do so, D55 (T_c =5503 K) or D75 (T_c =7504 K) should be used [1].

2.2 The spectral image processing algorithm

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. In continuous case the response of the human eye is:

$$c_i = \int_{\lambda\,\min}^{\lambda\,\max} S_i(\lambda) r(\lambda) l(\lambda) d\lambda \quad i = L, M, S \quad (7)$$

were L, M, and S are the responses of the long, medium, and short cones of the eye [4, 6].

- $S_i(\lambda)$ is the spectral energy density of the illuminant,
- $r(\lambda)$ is the fraction of the reflected illuminant energy,
- $l(\lambda)$ is the spectral distribution of light.

The image obtained using equation 7 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. 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). 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 (Fig. 4), and the relative absorptions of the human cones (Fig. 3) [4, 6].

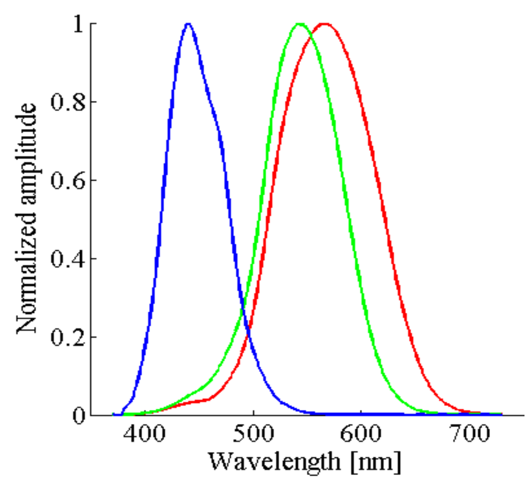

Fig. 3 The spectral response of the L, M, S cones

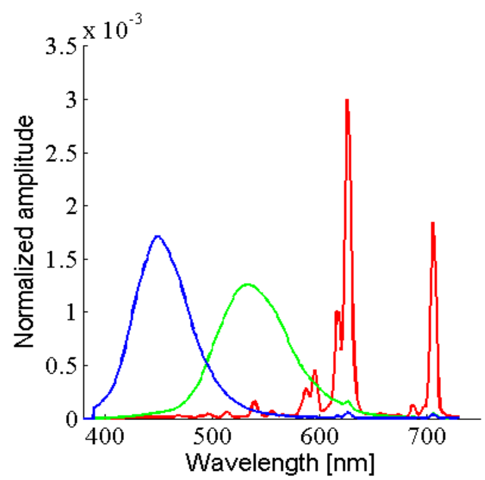

Fig. 4 The spectral response of the CRT monitor

Having this data, we can compute the 3 x 3 transformation that maps the linear intensity of the display R, G, B signals into the cone absorptions L, M, S [4, 6]

$$\begin{bmatrix} 14.0253 & -13.5154 & 0.7385 \\ -4.1468 & 10.1490 & -1.3618 \\ -0.1753 & -0.5663 & 7.3776 \end{bmatrix}. \quad (8)$$

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

$$V_{out} = V_{in}{}^{\gamma}. \quad (9)$$

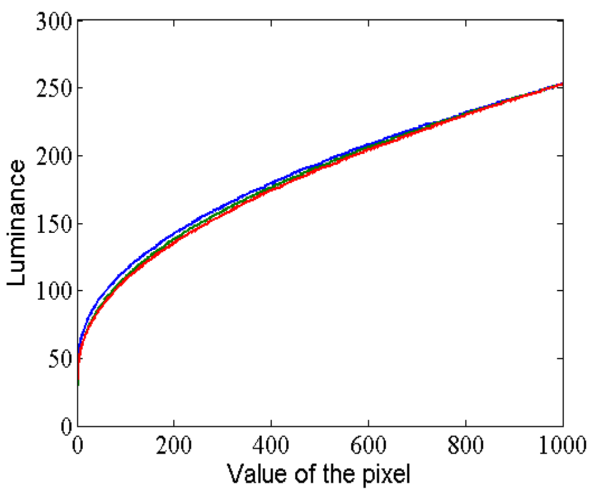

Fig. 5 The inverse gamma function

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.

2.3 The algorithm of illumination

In conformity with the equation (7-9) we have the next algorithm steps:

1. Load the data into Matlab (spectral image and the daylight spectral power distribution)
2. Using the input data, for each pixel compute the intensity of the reflected light energy at each given λ using equation 7.
3. We make compatibility between monitor possibility of colors generation and how the human eyes cones perceive the colors radiance using equation 8.
4. We make gamma correction in order to correct the monitor luminance using equation 9.

2.4 Simulation of the changes of colors across the daylight

Changes in the sun's altitude during the day cause the color of daylight to shift from a cool (bluish) tint at high noon to a warm (yellowish to reddish) tint after sunrise or before sunset. In order to simulate the changes of the color across the daylight, we use some of the spectral power distributions of the CIE daylights (Fig. 2): D41 (T_c = 4100 K) the daylight after sunrise, D55 (T_c = 5503 K) the noon sunlight and D65 (T_c = 6504 K) the noon daylight.

Fig.6 Tint of the daylight after sunrise

Fig.7 Tint of the noon sunlight

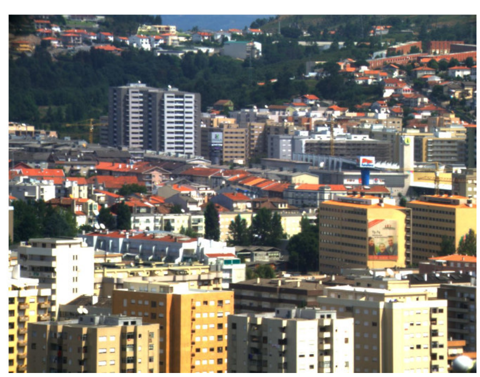

Fig.8 Tint of the noon daylight

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2.5 The human eye adaptation to illumination

The optics of the eye serves one purpose: to focus an image on the light sensitive retina. The ocular media is comprised of the cornea, aqueous humor, lens, vitreous humor, retinal vasculature, and macular pigment, are a cascaded series of color filters. These are called prereceptoral filters and act like filters which block short wavelength, the violet light, from reaching the retina. Across the visible spectrum, the cornea is nearly transparent, absorbing less than 10% of the incident light at 800 nm and less than 20% of the incident light at 400 nm. The aqueous and vitreous humors absorb less than 10% of the incident illumination at all wavelengths between 400 and 800 nm. The pigments of the lens absorb short wavelengths very strongly [3, 7]. The lens is the principal source of prereceptoral filtering. The colorless eye at birth, will gradually become yellows and darkens with age: the lens of an 80 years old eye, filters out approximately twice as much short wavelength light as the lens of a 20 year old eye.

The aperture into the eye or pupil is fringed by a light sensitive iris, spread over the front of the lens, which acts as a diaphragm to adjust the pupil from a minimum diameter of 2mm up to a maximum of 5mm (in the elderly) to 8mm (in young adults). This produces a change in pupil area from about 3.5 mm^2 to 20 to 35 mm^2, which provides an 87% to 95% reduction in the amount of light entering the eye. However, this represents a tiny fraction of the total range of illumination the eye can handle. Additional changes in luminance adaptation occur in the retina and brain across a span of several minutes; the iris makes prompt, momentary adjustments to changes in light intensity within the same light environment. By changing the aperture diameter we also change the quantity of light that pass in to the eye. The light which enters in to the eye is given by the light fall off law. Consequently, by modifying the aperture diameter we modify the light fall off [1-3].

The eyes, as any other optical instrument that has an aperture, suffer of light fall off. Cos4*f* law states that light fall-off in peripheral areas of the image increases as the angle of view increases. The peripheral image is formed by groups of light rays entering the eye's lens at a certain angle with respect to the optical axis, and the amount of light fall-off is proportional to the cosine of that angle raised to the fourth power.

$$E_i = \pi \cdot L \frac{1}{1+4(f/\#(1-m))^2}(\cos\phi)^4$$

where: L is source light radiation and m is the magnification.

Fig. 9 Tint of daylight CIE D75

Fig. 10 The effect of the window on the CIE D75 tint

Fig. 11 The perception of the light through the window

When the sun shines too much, the luminosity of the scene tends to be saturated. In our case (Fig. 9) the tint of daylight CIE D75 is too saturated. A simple method to protect the eye is to look through the windows. Windows are transparent glasses that insulate houses and cars from the exterior weather conditions [5]. We simulate the effect of the window Pilkington 4007 on the CIE D75 tint (Fig. 10). The spectrum of the windows attenuates about 15% of the incident light consequently the luminosity decrease and the scene do not shine so much. When the sun shines too much, the aperture adjusts its diameter and also the light fall off (Fig. 11).

3 Conclusion

The human eye is adapted to perceive the daylight. In this paper we compute the daylight spectral power distributions. Using the spectral distributions and the illumination algorithm we simulate the tint of the daylight in various moments of the day. When the sun shines too much, the eye makes its own adaptation to illumination. Also, we simulate the effect of the window on the CIE D75 tint and the perception of the light trough the window.

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