Illuminant spectrum maximizing the number of perceived colors in art paintings

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Abstract

The type of illumination used in museums is an important issue because of the damaging effects of light and because the visual impression of art works is critically influenced by the spectral profile and intensity of the illumination. The aim of this work was to determine computationally the spectrum of the illumination maximizing the number of colors perceived by normal observers when viewing art paintings. Hyperspectral images of eleven oil paintings were collected at the museum and the chromatic diversity under specific illuminants was estimated by computing the representation of the paintings in the CIELAB color space and by counting the number of non-empty unit cubes occupied by the corresponding color volume. An optimization algorithm was used to estimate the illuminant spectrum maximizing the number of colors for each painting. It was found that the optimized illuminant varied little with the painting and that it could produce a chromatic diversity about 25% higher than D_{65}. These results suggest that spectrally tuned light sources may improve appreciation of art paintings.

Introduction

A large variety of light sources, such as natural daylight, tungsten halogen lamps, or light sources that approximate natural daylight, like SoLux lamps, can be used to illuminate art paintings in museums [1]. Two aspects determining the type of illumination to be used are the damaging effects of the light on paintings and the visual impression it produces to an observer. To protect the paintings from the light damage light sources with low light intensities and low ultraviolet component should be used [1, 2]. To optimize the visual impression the spectral profile and intensity of the illuminant should be selected carefully [3, 4]. Laboratory experiments using postcards reproductions of paintings have shown that observers preferred illuminants with low correlated color temperature (CCT) [3]. Results of laboratory experiments using hyperspectral data from paintings for precise display on a calibrated CRT monitor have shown that daylight illumination with CCT of about 5000 K represent observers' preferences adequately [4]. On the other hand, results of psychophysical experiments using hyperspectral data from paintings [4, 5] suggested that observers' preference for specific illuminations could have been influenced by chromatic diversity, a complementary quantification of color rendering properties [6, 7]. Although chromatic diversity obtained with CIE standard illuminants has been characterized [4, 5, 8] it is not clear if illuminants with non-standard spectral composition may produce better chromatic diversity. The aim of this work was to determine computationally the spectral composition of the illumination maximizing the number of colors perceived by normal observers when viewing art paintings. The study was based on the analysis of hyperspectral images of eleven oil paintings.

Methods

Hyperspectral images of eleven oil paintings were collected at Museu Nogueira da Silva, Braga, Portugal. Figure 1 shows, as example, color pictures of 2 of the paintings analyzed (for pictures of the complete set see [4]).

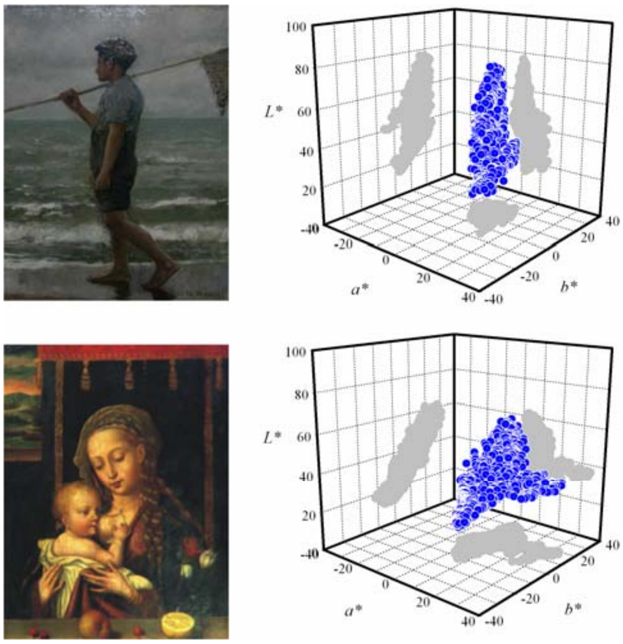

Figure 1 *Color pictures and the corresponding representations in the CIELAB color space for 2 of the 11 oil paintings analyzed.*

The hyperspectral system consisted of a low-noise Peltier-cooled digital camera with a spatial resolution of 1344×1024 pixels and 12-bit output (Hamamatsu, C4742-95-12ER, Hamamatsu Photonics K.K., Japan) and a fast-tunable liquid-crystal filter (VariSpec, model VS-VIS2-10HC-35-SQ, Cambridge Research & Instrumentation, Inc., MA, USA) mounted in front of the lens (for more details on the hyperspectral system see [9]). The hyperspectral digitalization was carried out over the range 400-720 nm at 10 nm intervals. The paintings were illuminated with low level SoLux illumination. The imaging distance and optical setup was such that the spatial resolution of the system was about 0.5 mm. The spectral reflectance of each pixel of the paintings was estimated from a gray reference surface present near the painting at the time of digitalization. Illuminant spatial non-uniformities were compensated using measurements of a uniform surface imaged in the same location and under the same illuminating conditions as the paintings [5]. The accuracy of the system in recovering spectral reflectance functions corresponded to an average spectral difference of 2%, to a colorimetric error on average of 1.3 when expressed by the CIE DE2000 color difference equation [10] and 2.2 when expressed in the CIELAB color space. These values were obtained with oil painted test samples [11] and represent an accuracy level within the acceptable range for visualization purposes [12, 13].

Chromatic diversity was first quantified by estimating the number of discernible colors in each painting rendered under D_{65}. The chromatic representation of the paintings in the approximately uniform CIELAB color space was computed and the number of non-empty unitary volumes in that space calculated. This procedure computes an approximated but reasonable estimation of the number of discernible colors [7, 14, 15]. The illuminant spectrum maximizing the number of discernible colors for each painting was then estimated using a simplex search method [16]. The spectrum of the D_{65} illuminant was used as a starting point of the algorithm.

Results

Figure 2 shows D_{65} and the optimized illuminant spectrum for each of the paintings represented. For presentation purposes data was normalized and smoothed. The optimized illuminants have common features with local maxima in the blue, green and red regions of the visible spectrum.

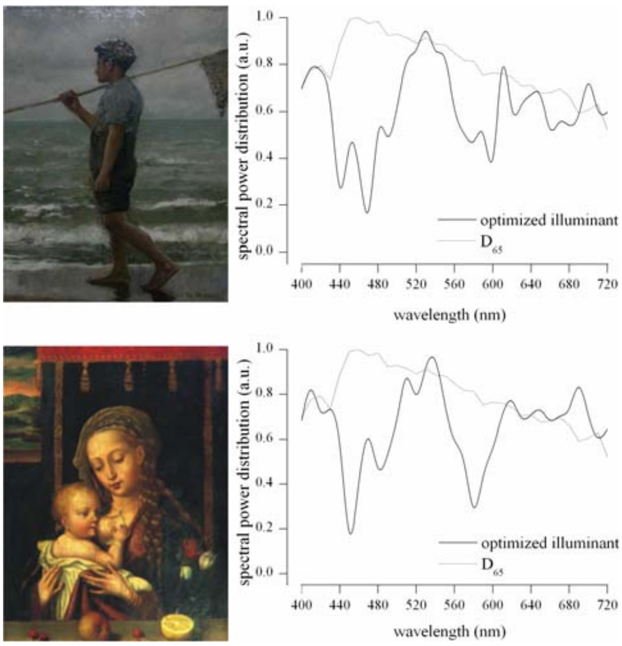

***Figure 2** D_{65} and the illuminant spectrum maximizing the number of discernible colors for each painting.*

The optimization routine produced similar results for the other paintings. Table 1 represents for each painting the increment in the number of discernible colors obtained with the optimized illuminant when D_{65} was used as reference. Enhancements in chromatic diversity were always considerable and in the range 17% - 40% and on average 26% better than D_{65}.

An average illuminant spectrum was obtained by averaging the optimized spectrum across paintings. The increments in chromatic diversity obtained with this average illuminant were in general similar to those obtained with the optimized illuminant and are also represented in Table 1.

Table 1: Increment in the number of discernible colors obtained with the optimized illuminant and with the average illuminant when D_{65} was used as reference. The paintings represented in Figure 1 and Figure 2 correspond to the paintings A and H in this table.

painting	optimized illuminant	average illuminant
A	40%	28%
B	29%	28%
C	31%	24%
D	22%	26%
E	17%	17%
F	20%	20%
G	22%	25%
H	33%	25%
I	21%	21%
J	27%	25%
K	19%	23%
average	**26%**	**24%**

Discussion

The main conclusion of this work is the possibility of obtaining considerable enhancements in chromatic diversity in artistic paintings by spectral tuning the illuminant. Here D_{65} was selected as the reference illuminant because it is the daylight producing best diversity with several paintings [5]. Also, because the optimized illuminant varied only moderately across paintings, a single light may be adequate for a museum or exhibitor room.

As this study concerns only computational estimation of chromatic diversity no psychophysics to determine actual observers' preferences was carried out. It is likely that other factors other than chromatic diversity may influence the visual impression and determine observers' preferences [4, 5].

Aspects related to the actual global appearance of the paintings when rendered under the optimized illuminants were also not considered. It may be possible that in some cases optimized chromatic diversity does not correspond to better visual impression and those aspects deserve further quantitative studies.

The results of this study justify recent attempts to develop and manufacture spectrally tuned light sources. White LED lamps are becoming of relative common use and, recently, a white light with a tunable power spectrum based on a dual-emitter light-emitting diode was reported [17]. Also, Optronic Laboratories, Inc., introduced a new light source capable of producing modulated emissions at single wavelength or broad spectrum based on Texas Instruments' Digital Light Projection technology (DLP) to offer a programmable and variable high intensity and high spectral resolution output.

Acknowledgements

This work was supported by the Centro de Física of Minho University, Braga, Portugal, by the Fundação para a Ciência e a Tecnologia (grant POCTI/EAT/55416/2004) and by MultiOpticas Unipessoal, Lda.

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Author Biography

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