Chromatic diversity index – an approach based on natural scenes

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Abstract

Common descriptors of light quality fail to predict the chromatic diversity produced by the same illuminant in different contexts such as images of natural scenes. The aim of this paper was to introduce a new index, capable of predicting illuminant-induced variations in the chromatic diversity off natural scenes. The spectral reflectance of each pixel of 50 images of natural scenes obtained using a hyperspectral imaging and the spectral reflectance of 1264 Munsell surfaces were converted into the CIELAB color space for each of the 55 illuminants and 5 light sources. The CIELAB volume was estimated by the convex hull method. The number of discernible colors was estimated by segmenting the CIELAB color volume into unitary cubes and by counting the number of non-empty cubes. High correlation was found between the CIELAB volume occupied by the Munsell surfaces, the number of discernible colors and CILEAB color volume of the colors of natural scenes. These results seem to indicate that a new illuminant chromatic diversity index based on natural scenes could be defined using the CIELAB volume of the Munsell surfaces.

Introduction

The spectral composition of the lighting or colored filters used in illumination can determine the quality of the chromatic experience for normal observers viewing artistic paintings or natural scenes [1-7].

Typically light sources are characterized by how much the colors produced approach those produced by daylight. This property, quantified by the color rendering index (CRI) [8], has, however, a number of limitations [8-10] and other quality measures have been considered [11-13]. In particular, the gamut area index (GAI) [14] that produces instead of direct color comparison an estimation of the extension of the chromatic gamut produced by a specific light source and, indirectly, measures the chromatic diversity produced. The CRI and the GAI indices had low correlation with the chromatic diversity expected in more complex scenarios as hyperspectral images of art paintings or natural scenes [15-16], making them inadequate to estimate the effect of the illumination in the chromatic diversity of such scenes. The number of discernible colors is a possible estimation of the chromatic diversity of complex scenarios [17-19].

A new metric of the effect of illuminants on the chromatic diversity of complex scenarios is necessary, if possible one that uses an easily available colorimetric data collection.

The main goal of this paper was to test the possibility of a chromatic diversity index based on Munsell surfaces but extensible to more complex scenarios like natural scenes. The colors of 1264 Munsell surfaces and 50 hyperspectral images of natural scenes were simulated under 60 illuminants or light sources and their effect in the CIELAB color volume and the number of discernible colors estimated as descriptors of chromatic diversity variations.

Methods

Figure 1 represents the images used in the present work. Data was acquired over the range 400-720 nm at 10 nm intervals using a fast-tunable liquid-crystal filter (Varispec, model VS-VIS2-10-HC-35-SQ, Cambridge Research & Instrumentation, Inc., Massachusetts) and a low-noise Peltier-cooled digital camera with a spatial resolution of 1344×1024 pixels and 12-bit output (Hamamatsu, model C4742-95-12ER, Hamamatsu Photonics K. K., Japan), (for more details on the hyperspectral system see [20]).

Figure 1 - Thumbnails of some of the 50 scenes analyzed in this study.

Hyperspectral data was calibrated using the spectrum of the light reflected from a gray surface present in the scene measure with a telespectroradimeter (SpectraColorimeter, PR-650, PhotoResearch Inc., Chatsworth, CA) just after image acquisition. The spectral radiance from each pixel of the image was then obtained after corrections for dark noise, spatial non-uniformities, stray light, and chromatic aberrations (for more details on these corrections see [20]). The reflectance information was obtained from the radiance data by using the illuminant information reflected on a gray reference presented in the scene at the time of acquisition, and by assuming that there were no illuminant spatial variations.

Munsell surfaces reflectance information was used as available at the Spectral Database, University of Joensuu Color Group (*http://spectral.joensuu.fi/*).

CIE Illuminant A and C and 21 D illuminants (CCT in the range 25,000 K to 3,600 K in steps of 1190.3 K) were used as daylight illuminants [21], 27 FL illuminants (FL1, FL2, FL3, FL4, FL5, FL6, FL7, FL8, FL9, FL10, FL11*, FL12, FL3.1, FL3.2, FL3.3, FL3.4, FL3.5, FL3.6, FL3.7, FL3.8, FL3.9, FL3.10, FL3.11, FL3.12, FL3.13, FL3.14, and FL3.15) as fluorescent lamps and 5 HP illuminants (HP1, HP2, HP3, HP4 and HP5) as high pressure discharge lamps. Five white LEDs (LXHL-BW02, LXHL-BW03, LXML-PWC1-0100, LXML-PWN1-0100 and LXML-PWW1-0060 from Luxeon, Philips Lumileds Lighting Company, USA) were used as light sources. These white LEDs were chosen because they are widely used and are commercialized by one of the main illumination companies and Figure 2 represents their normalized spectral power distribution.

The CIELAB color volume for each natural scene image and Munsell data was estimated assuming each reflectance rendered under the test illuminant considering the CIE 1931 Standard Colorimetric Observer [21].

The number of discernible colors was estimated by segmenting the CIELAB color volume of the natural scene into unitary cubes and by counting the number of non-empty unitary cubes, assuming that all the colors that rely inside the same cube could not be discernible.

The correspondent volume was estimated by using a convex hull algorithm by computing the smallest convex polyhedron containing all of the points of the CIELAB color volume, and by computing its volume.

Results

Figure 3 represents the comparison of the CIELAB color volumes obtained for the Munsell surfaces and the number of discernible colors for natural scenes as open circles and the CIELAB color volume of Munsell surfaces and the CIELAB color volume of natural scenes as open squares. Each point represents a particular illuminant with data averaged across scenes. Straight lines represent unweighted linear regressions to each correspondent data set, and quantities the proportion of variance R^2 accounted for in the regression for each case. Scales are divided by a factor of 10 000 for representation purposes.

Figure 4 to Figure 7 represents the same comparisons and data as Figure 3 with illuminant families separated as Daylight, Fluorescent and High Pressure discharge lamps illuminants and LED light sources, respectively

A very good degree of correlation between the CIELAB volumes of Munsell surfaces and the number of discernible colors of natural scenes and the CIELAB volumes of Munsell surfaces and the CIELAB volumes of the colors of the natural scenes was found for Daylight, Fluorescent and High Pressure discharge lamps illuminants. A considerable degree of correlation was also found for the number of discernible colors and the CIELAB volumes of Munsell surfaces when rendered under LED light sources but a poor correlation for the CIELAB volumes of the colors of the natural scenes and the CIELAB volumes of Munsell surfaces was found for LED light sources. In general, as represented in Figure 3, there is a very good correlation between the CIELAB volume of the Munsell surfaces and the CIELAB volumes of the colors of the natural scenes, and a good correlation for the CIELAB volume of the Munsell surfaces and the number of discernible colors of natural scenes.

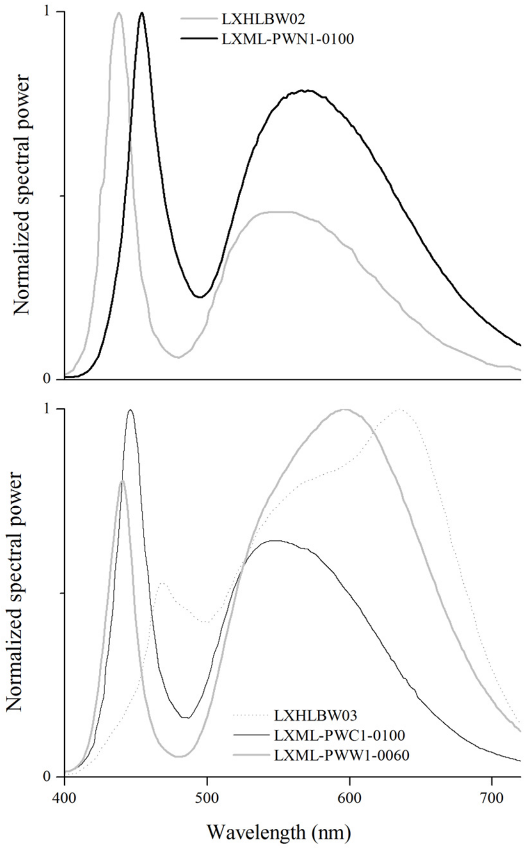

Figure 2 - Normalized spectral power distribution of the 5 white LEDs used (Luxeon, Philips Lumileds Lighting Company, USA).

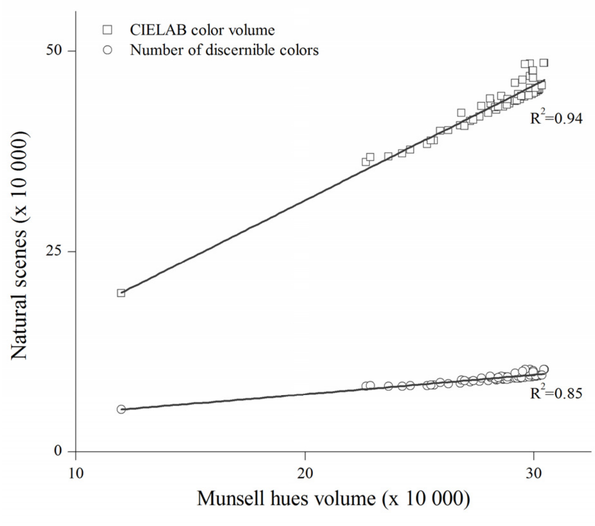

Figure 3 – Average CIELAB color volume (open squares) and number of discernible colors (open circles) of natural scenes as a function of the CIELAB volume of Munsell surfaces for all illuminants database. Straight lines represent unweighted linear regressions to each correspondent data set, and quantities the proportion of variance R2 accounted for in the regression for each case.

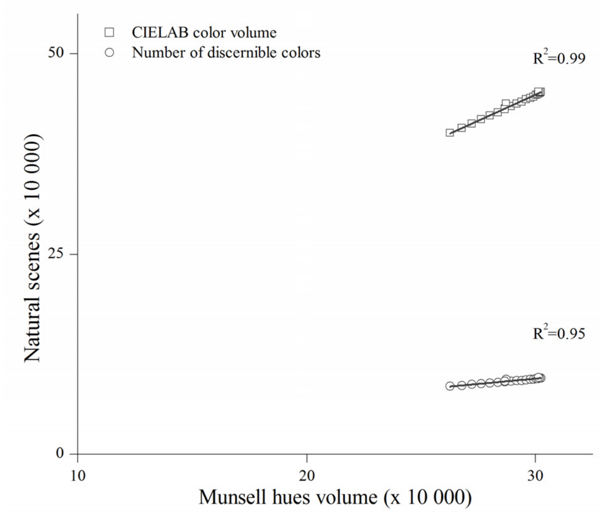

Figure 4 – Same as Figure 3 but for Daylight illuminants only.

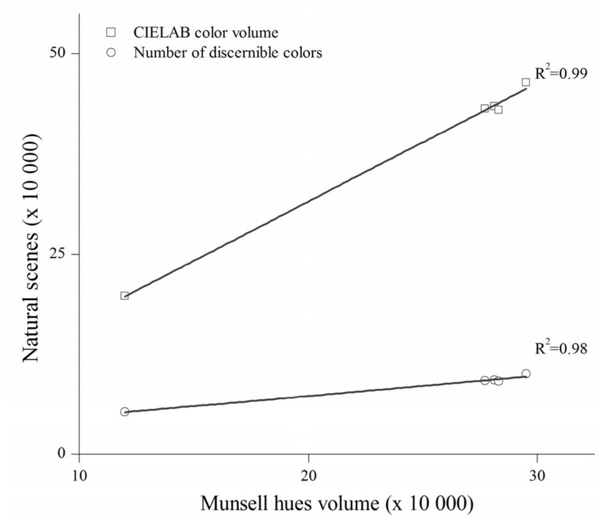

Figure 6 – Same as Figure 3 but for High Pressure discharge illuminants only.

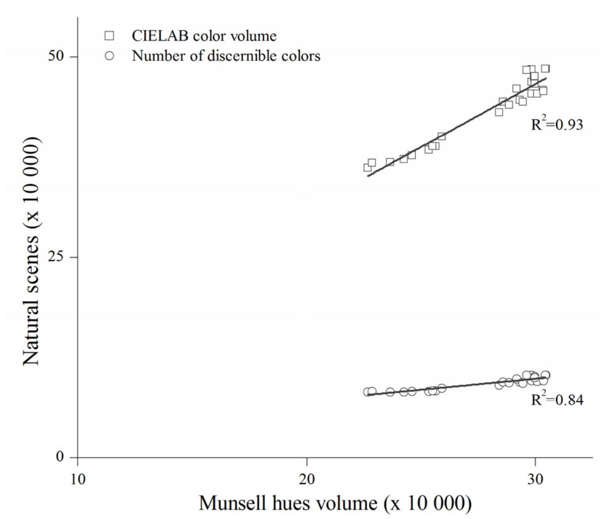

Figure 5 – Same as Figure 3 but for Fluorescent illuminants only.

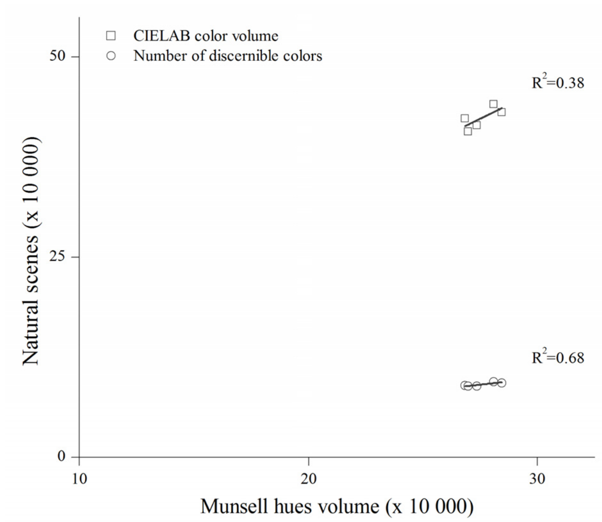

Figure 7 – Same as Figure 3 but for Led Light Sources only.

Conclusion and comment

In this work hyperspectral data of images of natural scenes and reflectance data of Munsell surfaces were used to estimate the chromatic variations between the two sets of data when rendered under different illuminants. A good correlation between the two data sets was found regardless of the different origins of the two databases. Such a result seems to indicate that the computation of the volume of the Munsell surfaces colors under a test illuminant is a good predictor of the effect of that illuminant in the chromatic variation of more complex scenes.

All the computations were done using the CIELAB color space, well known for its non-uniformities in particular in blue and gray areas [22-23]. Also, the segmentation of the color volume into unitary cubes assumes that all colors inside the same cube could not be distinguished, but in fact some pairs have a color difference $\Delta E^*ab > 1$ which are in fact discernible. The use of unitary spheres to segment the color volume can partially overcome this limitation, but some studies [19] suggests that relative estimates of the number of discernible colors are robust in relation to other methodologies that can be used to compute with great accuracy the number of discernible colors. The use of other uniform color spaces like de DIN99d [24] or the CIECAM02 [25] is not expected to produce significant variations in the results.

The number of discernible colors as a descriptor of the chromatic diversity was not used in the Munsell colors as the influence of different illuminants does not change considerably the number of discernible colors as they all are colorimetric distinguishable.

The good correlation between the estimated volume for the Munsell colors and for the natural scenes wasn't completed expected as natural scenes color volumes are not completely uniform as the distribution of the Munsell colors. Non-uniform empty spaces exist in the natural scenes color volume, ignored by the convex hull method. These color volumes were measured up only to compare equal quantities as the comparison of the number of discernible colors and the volume occupied by the Munsell colors could have been affected by the described empty volumes.

Comparisons of the number of discernible colors as an illuminant chromatic diversity descriptor with classical methods as the CRI and the GAI were done elsewhere [15-16].

Further testing should be done to understand the poor correlation under the LED light sources, and the influence of this chromatic diversity descriptor in color deficiency observers.

Despite these limitations the data presented here suggests that the chromatic variations produced by different spectral illuminants in natural scenes could be predicted using the Munsell surfaces variations under the same illumination.

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Author Biography

João Linhares received his MPhil in Optometry and Neuroscience from The University of Manchester, UK, (2006) and is currently a PhD Student at the Minho University, Portugal. His work has focused on trichromats, anomalous trichromats and dichromats chromatic diversity of hyperspectral images of natural scenes and the influence of colored filters, light sources or illuminants in such diversity.

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