Colour vision with natural images: physical and psychophysical aspects

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ABSTRACT

The goal of this work was to investigate the spectral and chromatic properties of natural scenes by analysis of hyperspectral imaging data and to relate those properties to human colour vision. With illuminant D_{65} the average chromaticity of the scenes in CIE (x, y) chromaticity space was distributed around the daylight locus. Changes of cone signals due to changes in the spectral composition of daylight were highly correlated over different points of scene. In psychophysical experiments where colour constancy was tested with stimuli derived from the hyperspectral images, observers were found to perform slightly better than with artificial stimuli based on Mondrian-like patterns. Natural scenes are chromatically more constrained than commonly assumed and testing colour vision with them may be less demanding on the visual system than with other more artificial stimuli.

1. INTRODUCTION

Colour vision has to adapt to a physical world which is constrained in the variation of surface spectral reflectances and spectral compositions of illuminants. The identification of these constraints and the quantification of their statistics can be properly determined only from precise spectral data from entire natural scenes. Some studies have already employed spectral techniques[1-3] but of limited spatial resolution. Recent technical developments have, however, had a significant impact on the possibility of extracting chromatic features of natural scenes with greater precision and fewer artefacts due, for example, to object movement. Fast hyperspectral imaging has made possible the analysis of the spatio-chromatic structure of natural complex scenes from urban, rural, and forest environments. This technique has also enabled the use of natural stimuli in colour-vision experiments, and, therefore, its evaluation in more natural conditions.

In the present work, fast hyperspectral imaging was used to assess a range of chromatic properties of natural scenes. The ability of observers to make surface-colour matches across computer-simulated versions of these scenes was also assessed as a measure of "colour constancy".

2. METHOD

A high-spatial-resolution hyperspectral imaging system was used to acquire data from natural scenes in the Minho region of Portugal. The imaging system was developed from an earlier device[3] and comprised a low-noise Peltier-cooled digital camera with a spatial resolution of 1344 × 1024 pixels (Hamamatsu, C4742-95-12ER) coupled to a fast-tuneable liquid-crystal filter (VariSpec, model VS-VIS2-10HC-35-SQ, Cambridge Research & Instrumentation, Inc., MA, USA) mounted in front of the lens. Spectral-radiance and spectral-reflectance functions at each pixel were estimated from neutral references located in the scene and calibration data from a telespectroradiometer. In some scenes a set of neutral spherical references were located in several regions of the scene to investigate the spatial and angular variations of the illuminant. Scenes were classified into two classes: those representing rural environments and those representing urban environments. Figure 1 shows one example of each class. Images were analysed in relation to luminance and chromaticity distributions, mean radiance and spectral reflectance, colour gamut, cone signals, and variation of the illuminant across the scenes.

In psychophysical experiments, pairs of images related by a spatially uniform illuminant change (25000 K or 4000 K daylight to 6700 K daylight) and a variable surface-reflectance change were presented to observers whose task was to detect whether the change was a true illuminant change. The ability to make those surface-colour judgements was summarized with a standard index, for which perfect colour constancy corresponds to unity and lower values signify poorer performance (zero being perfect inconstancy).

Figure 1: Example of a rural scene (left) and of an urban scene (right).

3. RESULTS

Figure 2 shows the average chromaticity in CIE (x, y) chromaticity space of several rural and urban scenes assumed illuminated by CIE standard illuminant D_{65}. The average chromaticities are not neutral and are distributed around the daylight locus. Figure 3 shows the distribution of chromaticities for rural and urban environments. In both cases the colour gamut of the scenes is constrained to a central region of the chromaticity diagram.

As in previous studies[4], cone excitations were estimated as a function of the illuminant in the scene and it was found that spatial ratios of cone signals due to changes in the spectral composition of daylight were almost invariant both for rural and urban environments.

The spectral variation of the illuminant across each scene was also investigated with the aid of small grey spheres located in various positions in each scene. Within the same scene, standard deviations of illumination chromaticities were less than 0.04 in CIE (x, y) units and about the same in both axis directions. They were a little larger for urban than for rural scenes. The CCT of the illumination within the same scene varied by about 4000 K and over all scenes from 4000 K to 8000 K.

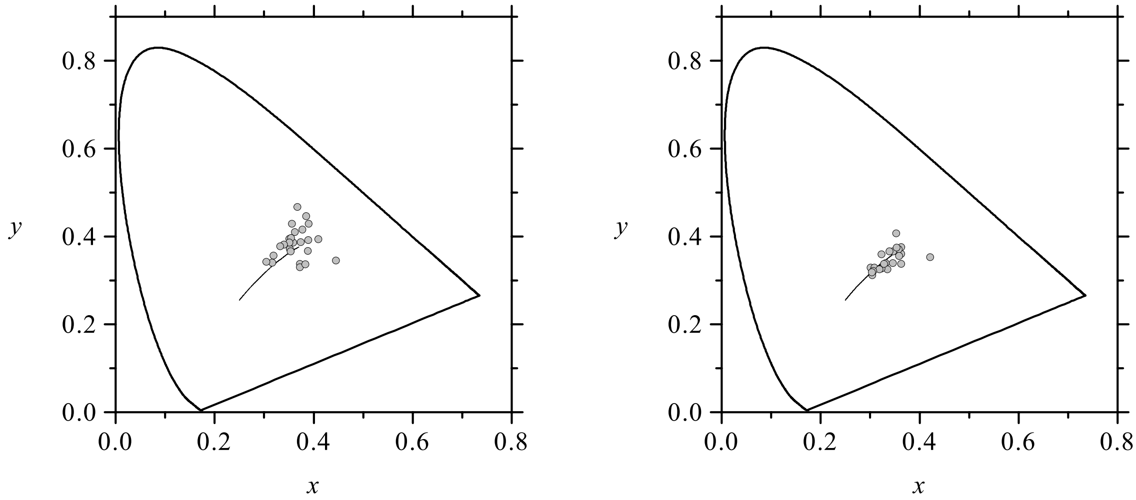

Figure 2: Average chromaticity CIE (x, y) of rural scenes (left) and urban scenes (right) assuming D_{65} as the illuminant. The central curved line represents the daylight locus.

In the psychophysical experiments, the mean constancy index over different scenes was 0.79 for the 25000 K initial illuminant and 0.76 for the 4000 K initial illuminant, with sample standard deviations of respectively 0.16 and 0.11. These index values are numerically slightly higher than those reported for Mondrian patterns with similar conditions of viewing[5]. Thus, surface-colour judgements with natural scenes are at least as good as those with artificial stimulus arrangements. Contrary to expectations, however, some of the most accurate surface-colour judgements of natural surfaces (index values 0.94–0.97) were with scenes where there was apparently least chromatic variation.

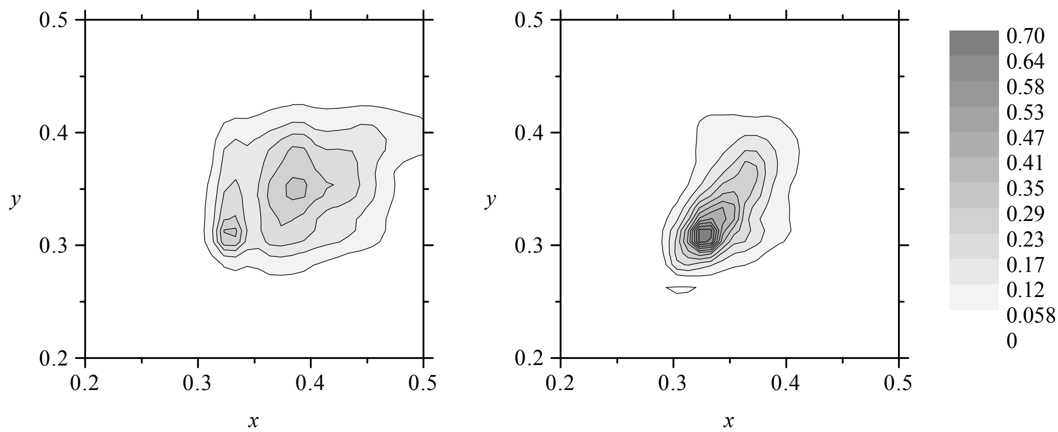

Figure 3: Distribution of chromaticities CIE (x, y) of rural scenes (left) and urban scenes (right).

4. CONCLUSIONS

Natural scenes are chromatically more constrained than commonly assumed. Moreover, psychophysical experiments using test stimuli based on these natural environments seem to be less demanding for the visual system than artificial stimuli.

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