Tracking Categorical Surface Colour Across Illuminant Changes In Natural Scenes

Kinjiro Amano, David H. Foster; Sensing, Imaging, and Signal Processing Group, School of Electrical and Electronic Engineering, University of Manchester; Manchester, UK

Abstract

How well can categorical colour perception be maintained in natural environments with varying illuminants? To address this question, a colour-naming experiment was performed with colour-monitor images of natural scenes simulated under two different daylights of correlated colour temperature 6500 K and 25000 K. Images were obtained from a set of hyperspectral data to enable the accurate control of illuminant and reflectance spectra. Each scene contained a spherical test surface whose digitally manipulated spectral reflectance coincided with that of a sample drawn randomly from approximately 430 Munsell reflectances grouped into eight colour categories, namely, red, green, blue, yellow, pink, purple, brown, and orange. Observers had to name the colour of the test surface in each image, presented for 1 s, by pressing one of nine computer keys corresponding to the eight categorical colour names and a neutral category. Focal colours were estimated from the peaks of the smoothed distributions of observers' naming responses in the CIE 1976 (u', v') chromaticity diagram. The effect of the illuminant change was quantified by a focal colour constancy index, with values 0 and 1 corresponding to no constancy and perfect constancy. Average levels of focal colour constancy were close to those from traditional measures of colour constancy, but with variation across categories and surface lightness. For blue and purple surfaces levels approached 0.9. For many surface colours, colour naming seems to be robust under illuminant changes and may help to anchor non-categorical judgements of arbitrary surface colours in natural scenes.

Introduction

The reliable recognition of object and surface colour depends on two perceptual phenomena: colour constancy and categorical colour perception. Colour constancy refers to the invariant perception of surface colour despite changes in the spectrum of the illumination [e.g., 1, 2]. Categorical colour perception refers to the tendency to perceive surface colours as members of a limited number of subsets, as illustrated by the eleven basic colour categories, believed to be an inherent and universal property of human colour vision [3-5], and for which there is some neurophysiological support [6, 7].

The interrelationship between these two phenomena has been investigated mainly with abstract coloured patterns [2, 8, 9]. But it is unclear how well categorical colour perception is maintained in more complex natural environments, where surfaces vary markedly in both spatial and chromatic contents.

It has been asserted that colour category boundaries are undistorted by changes in illuminations. Dorothea Jameson, for example, observed "I have no difficulty picking up the green notepad on my desk and not the blue one whether I do it in the daytime or at night with the study light on, or whether the blue and green notepads are resting on the bare surface of the desk, or one is on top of the orange journal, or the pile of papers that I have not yet filed". [10, p. 42]

Such everyday experiences seem to be based on direct and absolute inferences about surface colour. But this is sometimes difficult to quantify in laboratory experiments. Categorical colour perception has often been assessed by colour naming, in which an observer assigns a colour name to a test surface using either an unlimited range of terms or a prescribed finite set [2, 8], whereas colour constancy has often been measured by asymmetric colour matching, in which an observer adjusts the colour of a match surface under one illumination to appear the same as the colour of a test surface under different illumination, according to a given criterion [1, 11-13]. The former represents observers' direct judgements whereas the latter depends on relative judgements [14, 15]. Both have their advantages and disadvantages [14], but colour naming, in particular, may be
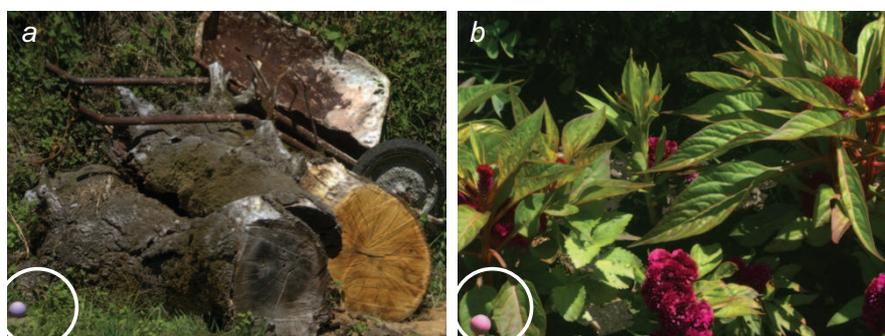
Figure 1. *Images of two natural scenes used in the experiment, (a) from a farm and (b) flowers and foliage. Two other scenes were of a garden and a house (not shown).In each scene, the test surface was a sphere (indicated by circles) whose surface was digitally replaced by a Munsell surface.*
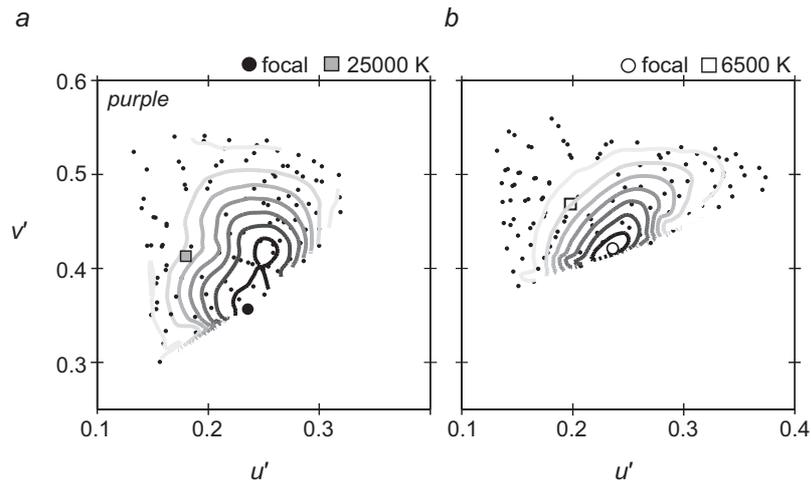
Figure 2. Distributions of "purple" responses with the flowers scene under a daylight with correlated colour temperature (a) 25000 K and (b) 6500 K (squares) at an intermediate lightness level, smoothed by loess to produce contours in the CIE 1976 (u', v') chromaticity diagram. The peaks of the distributions (circles) were taken as the focal colours.

biased by the limited set of colour names available. This problem may be circumvented by recording naming behaviour over a large repertoire of test colours so that, independent of the illuminant, there is always a good example of a basic colour category available. In this study, categorical colour naming was performed with images of natural scenes simulated under separate daylights, with correlated colour temperatures 25000K and 6500 K. The test surface was given up to 430 different colours grouped into eight colour categories, and whose surface reflectances were generated from Munsell reflectances [16].

It was found that for many surface colours in natural scenes colour constancy based on categorical colour naming was as good as that with asymmetric colour matching.

Methods

Apparatus

Images of natural scenes were presented on a 20-inch CRT display (GDM-F520, Sony Corp., Japan) controlled by a graphics workstation (Fuel, Silicon Graphics Inc., CA) with spatial resolution 1600 × 1200 pixels, refresh rate approx. 60 Hz, and intensity resolution 10 bits on each RGB gun. The display system was regularly calibrated with a telespectroradiometer (SpectraColorimeter, PR-650, Photo Research, Chatsworth, CA) to maintain the colorimetric accuracy. The experiment was conducted in a darkened room.

Stimuli

Images were generated from hyperspectral data to allow the accurate control of illuminant and reflectance spectra [17]. There were four scenes in all: one from a farm and another of some flowers and foliage are illustrated in Figure 1 (a) and (b); the other two scenes were garden and a house. The test surface was a sphere physically placed in the scenes, indicated by circles in Fig. 1, whose surface spectral reflectance was manipulated digitally. Images of the scenes were simulated under daylights of correlated colour temperature either 25000 K or 6500 K, corresponding to blue sky light and average daylight, respectively. These illuminants were selected so as to be compatible with earlier studies in which a surface-colour judgement task was performed [17]. The images on the screen

subtended approx. 18° × 13° and the test target approx. 1° visual angle, at a viewing distance of 1 m.

Procedure

The surface reflectance of the test surface was manipulated so as to coincide with that of a sample drawn from approximately 430 Munsell reflectances [16] with various Munsell Hue, Chroma, and Value (lightness), grouped into eight colour categories, namely, red, green, yellow, blue, pink, purple, brown, and orange [18], each of which contained approximately 60 surface colours. In each experimental session, one category group was tested (approximately 60 trials) for a particular scene.

In each trial, observers viewed each image for 1 s and then had to name the colour of the test surface by pressing one of nine computer keys corresponding to the eight categorical colour names and a neutral category (equivalent to black, grey, or white). Each of the eight colour-category groups was tested in a different session with each of the four natural scenes. The order of the eight groups and natural scenes was randomized over observers, and each of the surface colours was named twice in different sessions. Observers performed approximately 900 trials per scene. Observers were free to move their eyes during the presentation of the stimulus and there was no time limit for responses.

Observers

Twelve observers (5 female and 7 male, aged 22–40 years) took part in the experiment. All observers had normal colour vision verified with a series of clinical tests: the Farnsworth-Munsell 100-Hue Test; Ishihara pseudo-isochromatic plates; Rayleigh and Moreland anomaloscopy and luminance matching (Interzeag Color Vision meter 712, Schlieren, Switzerland). All observers had normal visual acuity and all except one were unaware of the purpose of the experiment.

Results and comment

The naming responses from all observers were pooled for each scene. Responses were then grouped into three levels (lower, intermediate, and higher) according to the lightness of the surface being judged so that each level comprised approximately the same number of samples.

At each lightness level, the response distribution was smoothed by a locally weighted polynomial regression, loess [19], in the CIE 1976 (u', v') chromaticity diagram. The bandwidth of the loess was determined by cross-validation. The estimated peaks of the distributions were taken as the foci of the colour categories, i.e. the focal colours.

As an example, Figure 2 shows the distributions of the responses "purple" at the intermediate lightness level for the flowers scene (Fig. 1b) under daylights of correlated colour temperature (a) 25000 K and (b) 6500 K. The coordinates of the illuminants are shown by filled and open squares, and those of the focal colours by filled and open circles in each panel. The naming distributions are shown by the contours, where the darker contours represent higher frequencies. The small dots show the coordinates of the Munsell samples at the selected lightness level, and reveal the displayable colour gamut.

The positions of the focal colours were similar to those in earlier studies [20-22], and did not necessarily fall at the centre of the naming distributions [5, 18]. Except for "brown", they tended to be saturated colours, and were therefore located close to the edge of the colour gamut (Fig. 2). This was also true for the other three natural scenes tested, and for the other lightness levels, i.e., the lower and higher levels, although the size of the displayable gamut varied [9, 23].

The illuminant-induced shifts of the focal colours in the farm and flowers scenes are shown by the arrows in Figure 3 (a) and (b), respectively. The positions of the focal colours (circles) shifted mainly in the direction of the illuminant change (squares), except for the category "green". The magnitude of the shift also varied over categories, with that for the categories "yellow" and "pink" for the flowers scene particularly small. Similar trends were evident in the other two scenes tested.

To quantify the effect of the illuminant change on categorical colour naming, a focal colour constancy index was defined based on the positions of the Munsell colours closest to the focal colours. Its schematic definition is given in Figure 4.

Let F1 and C1 be, respectively, the coordinates of a focal colour and the closest Munsell colour under one illuminant, 25000 K, and let F2 and C2 be the corresponding coordinates under the other illuminant, 6500 K. Then a shift from F2 by the offset between F1 and C1 defines a corrected coordinate F2′; that is, F2′ = F2 − (F1 − C1). Let a be the distance F2′ − C2 and b be the distance C1 − C2. Then the focal colour constancy index is given by 1 − a/b, where the values 0 and 1 correspond to no constancy and perfect constancy, as with the standard constancy index [1].
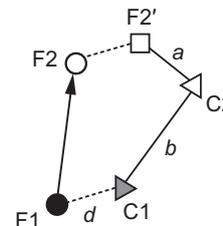
Figure 4. Schematic definition of focal-colour constancy index (see text).

Table 1 lists for each scene and colour category the resulting focal colour constancy indices at the intermediate lightness level. Focal-colour constancy varied with both test surface and scene, but indices for the categories "blue", "purple", and "pink" reached as high as 0.9. Overall, these values are similar to those in traditional measurements of colour constancy with Mondrian-like coloured patterns [1, 12, 13, 24] and with natural scenes [17]. The anomalous shift with the category "green" and reduced shift with the category "yellow" may have been due partly to constraints on the displayable gamut [9], which do not affect the other categories. For the flowers and house scenes, the index was not computable, as the corresponding Munusell colour C2 was unavailable within the gamut.
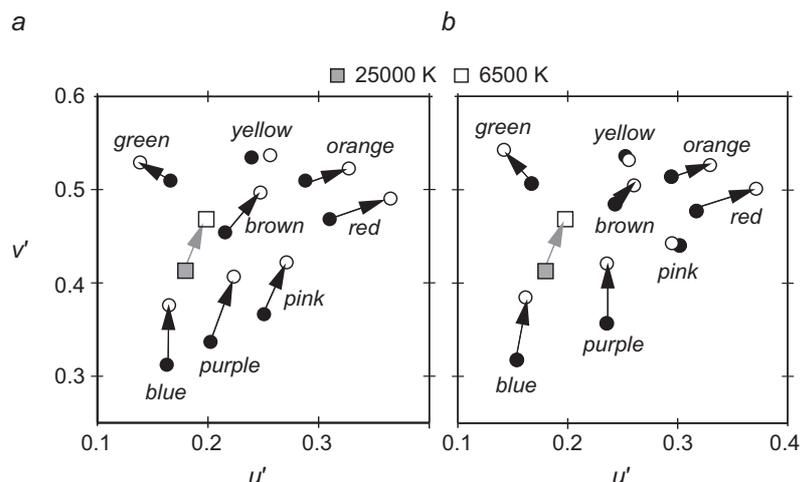
Figure 3. Shift of coordinates of focal colours under daylights of correlated colour temperature 25000 K (solid circles) and 6500 K (open circles) at an intermediate lightness level for (a) farm and (b) flowers scenes (Fig.1 a and b, respectively). The shift in illuminant is also indicated (solid and open squares).

Table 1. Focal colour constancy indices for four natural scenes.

natural scene	colour category							
	red	green	yellow	blue	pink	purple	brown	orange
farm	0.49	-0.44	0.40	0.89	0.71	0.95	0.85	0.56
flowers	0.48	-0.41	-	0.97	-0.05	0.54	0.64	0.65
garden	0.76	-0.95	0.30	0.88	0.31	0.74	0.89	0.61
house	0.47	0.65	-	0.92	0.91	0.86	0.60	0.59

The indices for the categories "blue", "purple", "brown" were almost the same at the other lightness levels (not shown); the index for the category "red" was better at the lower lightness level and that for "green" at the higher lightness level; for "pink" and "orange", it varied across scenes.

Conclusion

Categorical colour perception seems robust under illuminant changes, and for many surface colours average levels of colour constancy were similar to those obtained with asymmetric colour matching, with blue and purple surfaces being particularly stable. Although both scene content and lightness of surfaces appear to influence performance, absolute judgements of surface colour may serve to anchor non-categorical judgements of arbitrary surface colour within natural scenes.

Acknowledgements

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Author Biography

Kinjiro Amano (k.amano@manchester.ac.uk) received his Ph.D in 1998 from the Tokyo Institute of Technology, Japan. He has worked at Aston University and UMIST, and is currently at the University of Manchester. His research work has concentrated on the psychophysics of human colour perception, in particular colour constancy.