A method to derive local colour differences tolerances in complex images

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ABSTRACT

A methodology of evaluation of local colour differences in complex images is reported. A concept of image colour centres is proposed, and methodology of practical implementation of this concept is described. The feasibility of the developed methodology was tested in a pilot study with printed images, for one colour centre and colour difference limited to the Hue dimension (CIELAB h). The results show that colour context is likely to influence the observer's judgment. Lower threshold values can be expected for local colour differences then for global ones; and these thresholds cannot be assumed to be symmetrical about the colour centre.

1. INTRODUCTION

Standard methods[1-3] for evaluation of colour differences are based on studies with simple colour stimuli, that is – uniform samples on uniform neutral background. In investigation of colour differences in images the situation is different: images have continuously varying shades, shapes and dimensions, and colours are placed in varying colour surroundings. In addition, there are various psychological factors which can affect the perception of colour differences: the content of the image, or presence of familiar objects for which the observer can have some expectations of their colour.

One common approach to the evaluation of colour differences in images is to consider each picture element – the pixel – as an independent simple stimulus. Then, the total colour difference between two complex stimuli (the images) can be calculated "globally" as an average colour difference between the corresponding pixels. Such "global" differences between images can be introduced by the imaging devices (dot gain, density drift); a number of studies on the subject have been reported.[4-7] However, Hong *et al*[8] have shown that a conventional technique of calculating colour error by averaging it in a pixel-by-pixel basis does not adequately represent the perceived difference.

The development of colour management technologies introduced a new kind of colour drifts in images: the "local" ones. Unlike the global differences, they are introduced by software elements such as device characterisation and gamut mapping algorithms.[8] Colour drifts of varying magnitude and direction can occur in different image areas, resulting in colours across the image to be reproduced with varying degree of accuracy.

The aim of the reported study[9] was to develop a methodology for the evaluation of local colour differences in images. This methodology includes the adoption of the concept of *colour centres* from the studies of colour differences with simple stimuli. We define the criteria for the choice of the centres, as well as the choice of the test images and techniques for their manipulation. The effect of the image content and the colour context are considered. The defined methods are implemented in the a category judgment psychophysical experiment, with the use of locally-modified digital images reproduced by ink-jet printing.

2. METHOD

In the method we propose, we define a number of concepts which are unique to the investigation of colour differences in images: "Image Colour Centre", "Image Region of Interest" and "Colour Context".

The choice of colour centres in experiments on colour tolerances in simple stimuli was guided by the CIE guidelines.[10,11] These guidelines were developed for testing the CIELAB space uniformity, and therefore have defined number of centres which uniformly sample the colour space. The task of the experiments with images is different: it is to investigate the sensitivity to colour differences in areas of varying shapes and shades and placed in different contexts. Furthermore, unlike in the case of

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Figure 1: Images used in the experiment. **A:** “Bride”, **B:** “Harbour”, **C:** “Abstract”. Black dots mark the points were the spectrophotometric measurement of the prints has been taken.

simple stimuli, some colours in images are considered to be more important than others. These are the so-called “memory colours”: skin, foliage and sky. Therefore, it seems reasonable to adopt these colours as the *Image Colour Centres* for investigation of colour tolerances in complex stimuli.

Having described this concept, a universal numerical definition of image colour centres is still difficult due to variation in colours of the real objects, as well as the cultural differences in preferred reproduction colour. Therefore a simplified approach is proposed as a starting point: we take a set of international standard test images defined in terms of the colorimetric values, and identify in these images the *Regions of Interest* (*ROI*): face, sky, grass. The colour centre would be the mean colour in these areas, and the colour region would be the distribution of colours in these areas.

The *Colour Context* defines the psychological property of the colour under investigation. It is the property of the ROI: the nature of the objects in it, relationship with their colour, size and spatial arrangement. For example, the colour of the face, and the colour of the building painted with the colour of the skin could have different context within the same image. In order to investigate the effect of the colour context on the perceived colour difference, we place the same colour in different situations. For the same example of the skin colour, these situations would be: a) the colour in its natural context (e.g. a portrait); b) the colour disconnected from its natural context, where natural objects are depicted (e.g. a building coloured with skintone colour); c) the colour disconnected from any recognisable context whatsoever (e.g. an abstract image).

In our study, we investigated the sensitivity to the Hue differences in the colour centre corresponding to the colour of the skin. Numerically, the centre was specified as the mean CIELAB coordinates in the ROI defining the face area in the “Bride” image from the SHIPP[12] standard image set (Fig. 1A); this image was also used as the test image for the colour in its natural context. The same colour of the skin was applied to a building in another SHIPP image (“Harbour”) (Fig.1B) in such a way that the variations of Lightness L* and Chroma C* and Hue h are in the range similar to the one in the ROI of the “Bride” image. The third image was an abstract one, in which the central area was coloured with the skin colour according to the same principle (Fig.1C). The sizes of the ROI in the three images were approximately the same, about 10% of the image, which corresponded to approximately 5° viewing angle in our experimental setup. The “Bride” image was the last in the sequence of the observations, which means that observers were not aware of the colour being the “skintone” while they made the observations of the other two images.

The colour shifts were applied selectively on the ROI of the images, in CIELAB h positive and negative directions. The magnitude of the shifts was in the range of -3 to +3 CIELAB ΔH^* units, in increments of approximately 0.3. The colour of the ink-jet prints was assessed by direct spectrophotometric measurement of the ROI using a punched template as illustrated in the in Figure 1.

A category judgement psychophysical experiment was performed, during which 16 observers judged 63 prints divided into three groups. Each group of prints consisted of the “Original” and the 20 “reproductions” of it – 10 for each (positive and negative) direction of the Hue shift. The reproductions were compared in random order with the original, and the observers’ task was to assign each reproduction one of the categories according to the perceived difference between them: “Difference not perceptible”, “Difference just perceptible”, “Difference perceptible but acceptable” and “Difference not acceptable”. The perceptibility threshold was defined as the boundary between the categories “Not Perceptible” and “Just Perceptible”, and the acceptability threshold – as the boundary between the categories “Perceptible but Acceptable” and “Not Acceptable”. The boundaries of the categories were determined from the experimental data by the application of Probit analysis.

3. RESULTS

The results show that significantly lower threshold values can be expected for local colour differences in images than for global ones. For the cases where statistically reliable results could be derived, the perceptibility thresholds for the given experimental conditions were found to be in the range of 0.84 to 1.19 CIELAB units. Stokes[6] reported values in the range of 1.5-2.5 CIELAB units, and Uroz[7] – in the range of 3.9-4.8 CIELAB units, both for systematically globally altered images. On the other hand, our figures are in agreement with the ones reported by Quao *et al*[13] for the for perceptibility of Hue colour differences in simple stimuli.

The values of acceptability thresholds lie in the range of 2.03-4.51 CIELAB units. These values are smaller then ones derived by Stokes[6] (up to 6), but partially agree with Pointer's,[14] who reported colour difference at 100% acceptability to be about 3 CIELAB units.

The setup of the current experiment was significantly different from the mentioned above in two points: the colours of the images were manipulated locally, and the direction of the manipulation was restricted to CIELAB h. Also, the ΔE_{ab} as a single number representation of colour difference is somewhat ambiguous, as it does not give any information about direction of the difference in terms of perceptual attributes: Lightness, Chroma and Hue. Therefore comparison between results of different experiments just in terms of CIELAB units does not always seem adequate.

Strong dependence of the CIELAB colour tolerances on the hue angle was previously reported,[13] therefore the current results cannot be generalised to any other colour but the one which was tested.

The results suggest that the colour context is likely to affect the perceptibility and acceptability of local colour differences. The differences are especially apparent between the portrait image “Bride” and the other two images – as can be seen on the Fig. 2: for the same ΔE_{ab} value, observers tend to assign higher categories to the portrait image. However, the data from the pilot experiment is too limited to generalise the result.

In experiments on perception of colour differences, thresholds are generally assumed to be symmetrical about the colour centre. Our results question the validity of this assumption. Figure 2 shows the plot of the average category assigned by the observer to the printed image versus the average ΔE_{ab} measured on the ROI of the same image, where the score value of 0 stands for “Not Perceptible” category, and 3 stands for “Unacceptable”. If the thresholds were symmetrical about the colour centre, the two sets of data would completely overlap. However, the plots show that, for all the images, samples having the same colour difference from the “original” tend to be assigned to a higher category if the direction of the hue shift is positive (green hue shift) than if the direction is negative (red hue shift). Exact numeric evaluation of this asymmetry could not be made due to insufficient data. However, the values for boundary between “Just Perceptible” and “Perceptible but acceptable” are almost twice as high for “Bride” images altered in negative (red) hue direction that in positive; for the abstract image the ratio is 72%, and for the “Harbour” image - 67%.

This asymmetry in colour thresholds is rather surprising. Although we could intuitively assume that observers would prefer reddish face colour over the greenish one, the reason for preferring reddish buildings and abstract pictures over the greenish ones is not obvious. No reference to studies reproducing the same effect could be found in the literature.

A survey was performed in order to learn about the observer's methods for evaluating the images. Most of the observers used different tactics for comparing the realistic and the abstract images: in the realistic images the ROI was evaluated as a whole, while in the abstract image observers tended to concentrate on the groups of squares of similar colour forming approximately uniform areas. Also, many observers noted that, in the realistic images, they considered the slight colour variations within the ROI as more important – for example the areas of make-up in the “Bride” image, or smooth shadows on the building's wall in the “Harbour” image.

4. CONCLUSIONS

A method of visual evaluation of local colour differences in images is proposed, and the results of the method implemented in a pilot experiment are reported. The results suggest that significantly higher sensitivity - in acceptability and perceptibility terms - can be expected for Hue local changes in images than global Chroma and Lightness changes in complex images. Symmetry about the colour centre cannot be assumed for thresholds in the opposite directions of hue differences - for either perceptibility or acceptability thresholds. Colour context is likely to affect the magnitude of perceptibility and acceptability of local colour differences, however, the data from the pilot experiment is too limited to generalise the result.

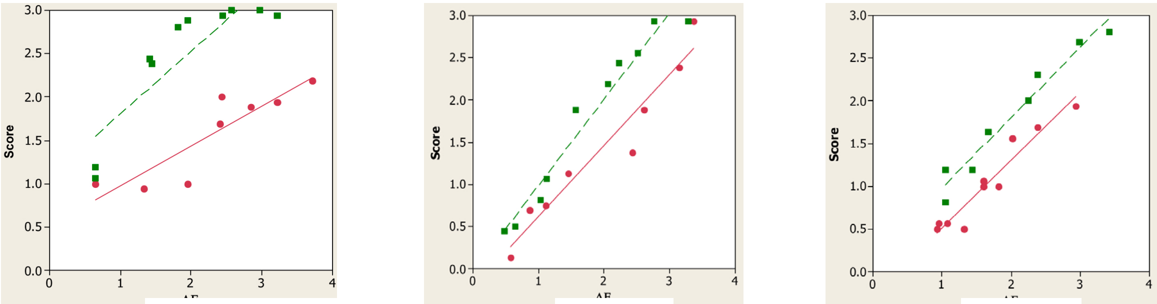

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Figure 2: Scatter plots of image score versus colour difference from the original. A: “Bride”, B: “Harbour”, C: “Abstract”. Squares indicate Hue shift to the positive – Green - direction; circles indicate the negative – Red – direction.

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