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Colour Image Enhancement using Perceptual Saturation and Vividness

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Abstract

A perceptual study was conducted to enhance colour image quality in terms of naturalness and preference using perceptual scales of saturation and vividness. Saturation scale has been extensively used for this purpose while vividness has been little used. We used perceptual scales of a recently developed colour appearance model based on $J_za_zb_z$ uniform colour space. A two-fold aim of the study was (i) to test performance of recently developed perceptual scales of saturation and vividness compared with previously used hypothetical models and (ii) to compare performance and chose one of saturation and vividness scales for colour image enhancement in future. Test images were first transformed to $J_za_zb_z$ colour space and their saturation and vividness were then decreased or increased to obtain 6 different variants of the image. Categorical judgment method was used to judge preference and naturalness of different variants of the test images and results are reported.

Introduction

Research on colour image enhancement has been under investigation for more than two decades and scientists have been trying to find a way to increase the perceptual quality of colour images by manipulating colour attributes. Fedorovskaya *et al.* [1], investigated chroma variations in 1997 to enhance perceptual image quality. Recently, Zhu *et al.* [2], performed an experiment to investigate performance of different colour scales including chroma, hue, lightness contrast, chroma contrast, vividness, depth and clarity. They used hypothetical formulae for vividness, depth and clarity, proposed by Berns [3]. Gong *et al.* [4], developed a number of models to enhance perceptual quality of colour images on mobile phone displays. Similarly, many other studies have investigated different colour scales to enhance image quality based on attributes of either CIELAB or CIECAM02 and tested for different image quality attributes e.g., naturalness, preference, contrast etc. [5, 6]. The work of Choi *et al.* [7], illustrated that naturalness is the most important scale for colour image quality, followed by colourfulness and contrast. Zeng and Luo [8] studied the skin colour and then developed models and algorithms for enhancement of the skin colour in terms of preference. Hence naturalness and preference are thought to be two more powerful image quality attributes.

The saturation and vividness scales were developed based on lightness and chroma attributes of the colour appearance model recently proposed by Safdar *et al.* [10], and are given in Equations (1) and (2), respectively. These two equation were derived based on experimental data produced by Cho *et al.* [11]. Many colour scales can be effective in image enhancement, only saturation and vividness scales were used to enhance colour images naturalness and preference in the current study.

$$\mathrm{S} = 20 + \sqrt{(J-55)^2 + (C)^2} \tag{1}$$

$$\mathrm{V} = 20 + 0.82\sqrt{(J-73)^2 + (C)^2} \tag{2}$$

A perceptual experiment was conducted and observers were asked to judge the degree of preference and naturalness for each variant of test images. One of the objectives was to follow a perceptual experiment that was performed by Zhu *et al.* [2], using same image set but changing the colour attributes to perceptual models of saturation and vividness instead of hypothetical scales. Another aim was to analyze the effectiveness of saturation and vividness on the perceived naturalness and preference.

Method

Test Images

We used an image set of 8 images comprising of wide range of colour contents including green grass, sky, trees, animals, human skin colour, water, flowers, fruits etc. Seven out of the eight images were same as used by Zhu *et al.* [2], and eighth one was different but having similar skin colour contents. We name these eight images as Chinese Woman, Banana, Apple, Blue Sky, Green Grass, Orange, Red Rose, and Red Tops, as shown in Fig. 1.

Image Calculation

Test images were manipulated by changing saturation and vividness using their perceptual scales in $J_za_zb_z$ colour space. For a given image, five manipulations were done for each of saturation and vividness independently. Decreasing vividness once and increasing four times with different decrements/increments gives six different levels of vividness (an image with decreased vividness, the original, and four images with different levels of increased vividness). Manipulations were done in terms of differnt percentages (-5%, $+5\%$, $+10\%$, $+15\%$, $+20\%$) of the given vividness. Fig. 2 shows 6 different levels of vividness of the Blue Sky image. Exactly same procedure was used for manipulations using the saturation scale.

Note that we obtained 6 different levels of vividness and 6 different levels of saturation for each image. So, there are 11 different variations (because the original image appears once only) for each test image. In total, 88 images were judged twice and 176 (8 original images x 11 variations of each original image x 2 image quality attributes) judgments were made by each observer.

Experimental Procedure

The experiment was conducted on a calibrated BenQ SW320 display. The distance between the monitor screen and observer eyes was maintained about 60cm. All the images were displayed on a neutral grey background. Categorical judgment method was used to scale image naturalness and preference on a scale of 1-10. Total 13 observers (6 males and 7 females from countries including Germany, Netherlands, France, Kosovo, Albania and Norway) with an average age of 22 years participated in the experiment. The experiment was divided into two phases with at least 5 minutes break between two phases. Average time

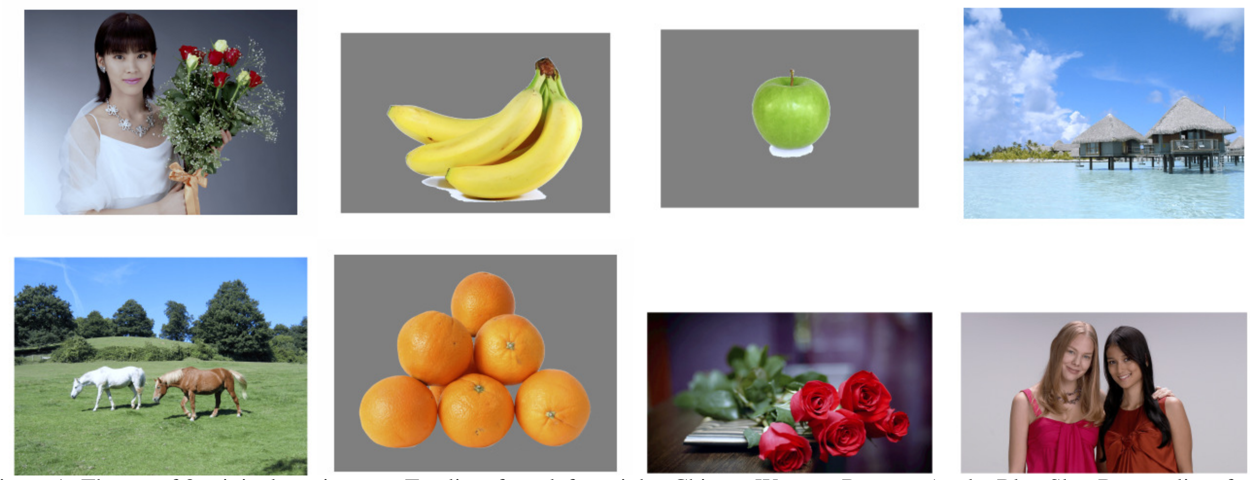

Figure 1: The set of 8 original test images. Top line, from left to right: Chinese Woman, Banana, Apple, Blue Sky. Bottom line, from left to right: Green Grass, Orange, Red Rose, Red Tops.

taken by observers to perform the whole experiment was between 35 to 45 minutes. Naturalness was scaled in the phase-1 and preference in the phase-2. This was done to avoid confusion between the definitions of two different image quality attributes. For example, if observers were asked to judge naturalness and preference at the same time, they might focus on only one scale and give same score to both.

Before starting the experiment, observers were given some instructions about the experiment and were briefed on the definition of the image quality attribute to focus on before starting each phase. Observers were asked to judge the colour image quality according to its perceived naturalness using a scale from 1 to 10, where 1 means the lowest degree of naturalness (i.e., the image looks completely unnatural), and 10 means the highest degree of naturalness (i.e., the image looks perfectly natural). Similar instructions were given for scaling preference.

Results and Discussions

In this section, we will first describe results obtained from the experiment in terms of scores between 1 to 10 for both image quality attributes for variations in saturation and vividness and then we will discuss results and provide comparison on performance of different attributes.

The observer ratings for naturalness and preference for various levels of saturation are shown in Fig. 3. It can be observed from Fig. 3 that an inverted U-shaped curve is obtained which shows that decrease in saturation decreases both naturalness and preference and increasing saturation up to a certain level increases preference but not naturalness. When saturation is increased beyond a certain level, observe scores for both naturalness and preference start decaying. This also correlate with results of many previous studies that people tend to prefer more colourful images even if they look unnatural.

The results showed that highest score was given to the original image for both preference and naturalness for variation in saturation. When analyzing individual images, four images (Green Grass, Apple, Orange and Red Tops) obtained a better preference with 5% more saturation than the original while 3 images (Green Grass, Apple and Chinese Woman) had better scores for naturalness with 5% increased saturation. It might depend on the

Figure 2: Manipulation of Blue Sky image based on the vividness scale. Top line, from left to right: -5%, 0%, $+5\%$. Bottom line, from left to right: $+10\%$, $+15\%$, $+20\%$.

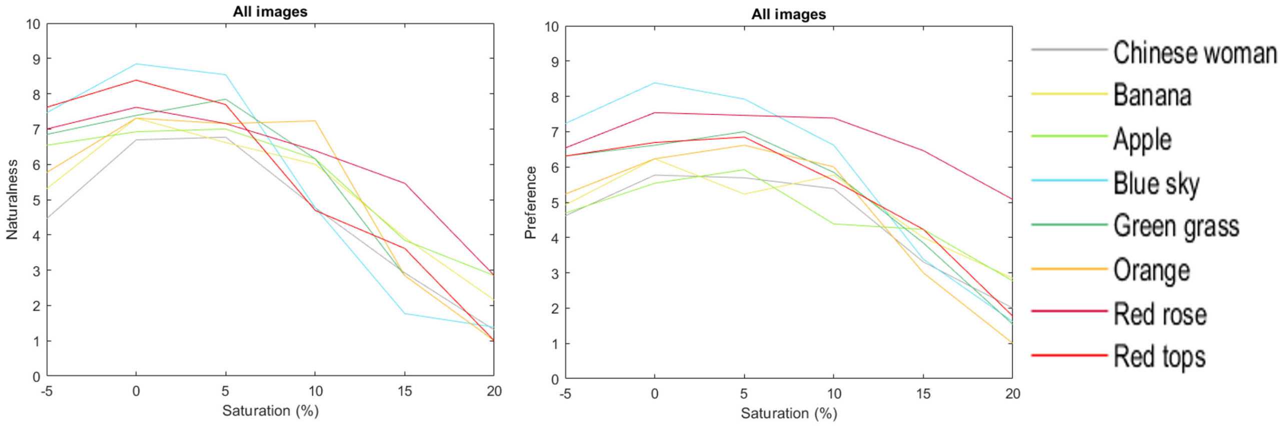

Figure 3: The left plot represents observer scores of naturalness (from 1 to 10) for the 8 test images with various levels of saturation. The right plot shows observer scores for preference.

original saturation of the image, or it could also depend on the image contents. As Zhu *et al.* [1], mentioned that depending on the contents of the image, people will prefer either more or less colourful images.

While analyzing results for images with varied perceptual vividness, inverted U-shaped patterns were observed similar to those for saturation but increase in vividness was proven to be more effective for both naturalness and preference compared with saturation as shown in Fig. 4. The main advantage of using vividness scale instead of saturation scale is that, on average, most preferred and most natural images are those with 5% increased vividness compared with all other variants. In other words, Fig. 4 depicts that, vividness increased by 5% not only improves colour image quality in terms of preference but also naturalness. Hence perceptual vividness scale gave better performance compared with saturation to improve image quality in terms of naturalness and preference.

To compare performance of perceptual scales of saturation and vividness to enhance colour image quality in terms of naturalness and preference, we subtracted the mean score of each original image from the best score and resulting scores are plotted in Fig. 5. Plots in Fig. 5 show that the overall scores are better with an increase in vividness for both preference and naturalness. Saturation increased by 5% gives insignificantly better results compared with original image for preference but the naturalness of the original images was scored higher than those with any level of variation in saturation. Whereas, a 5% increase in vividness caused higher scores for both naturalness and preference as shown in Fig. 5. In a previous study by Zhu *et al.* [2], the overall scores for preference and naturalness were higher for the original image compared with manipulated images. Our results are more consistent and contradict with Zhu *et al.* [2] and are encouraging for the use of vividness scale for colour image enhancement. The reason behind this seems that we used perceptual scales developed based on a uniform colour space [9, 10] instead of hypothetical scales used in the study by Zhu *et al.* [2].

Conclusions

In this study, perceptual attributes of saturation and vividness were used to enhance colour image quality in terms of naturalness and preference. Eight different colour images were manipulated and six different levels of saturation and vividness were obtained. It was found that increase in saturation may improve preference but not naturalness. Whereas, a certain increase in vividness can improve both naturalness and preference which are most important attributes of the colour image quality. Hence we recommend to use perceptual vividness scale in order to enhance image quality in terms of naturalness and preference.

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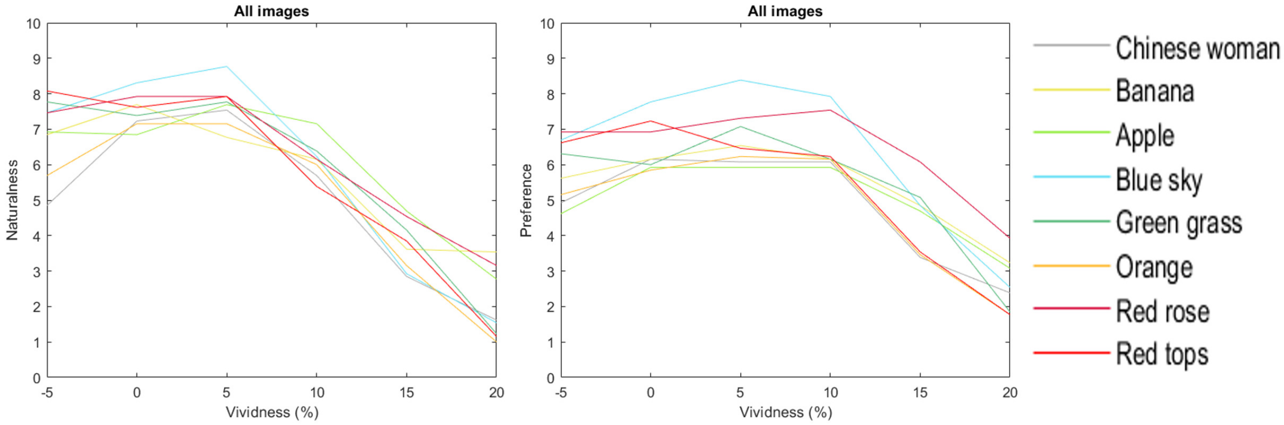

Figure 4: The left plot represents observer scores of naturalness (from 1 to 10) for the 8 test images with various levels of vividness. The right plot shows observer scores for preference.

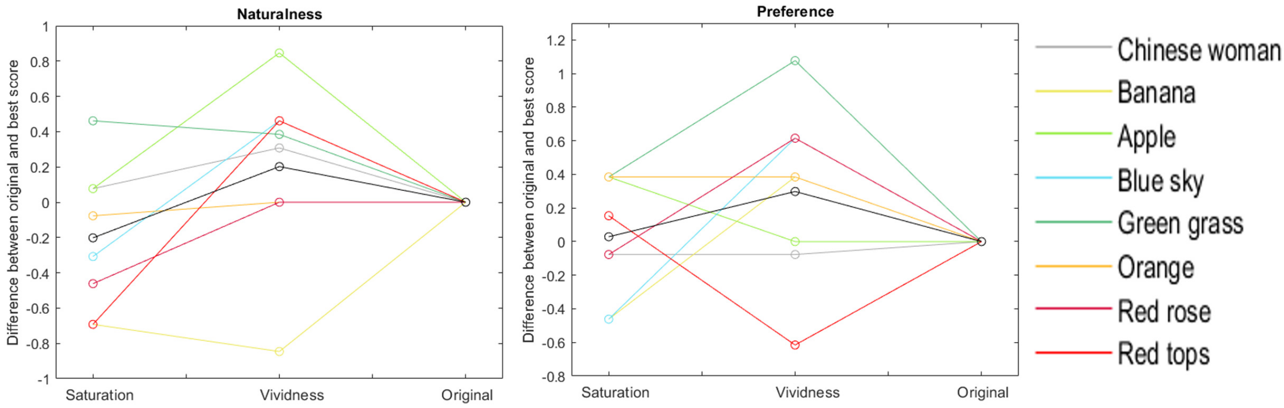

Figure 5: Plots of the difference of scores between the best score given to those of manipulation images and the score given to the original images. Left plot shows results for naturalness and right one for preference.

Author Biography

Dr. Muhammad Safdar received his M.Phil in Electronics from Quaid-i-Azam University in Islamabad, Pakistan (2011), and PhD in Colour and Imaging Science from Zhejiang University in Hangzhou, China (2017). He is currently working as ERCIM "Alain Bensoussan" Postdoc Fellow at The Norwegian Colour and Visual Computing Laboratory, NTNU in Gjøvik, Norway. He has (co-) authored more than 25 publications in the field of colour and imaging science. His research interests include colour theory, colour imaging, spectral imaging, and colour appearance.