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The Effectiveness of Colour Appearance Attributes for Enhancing Image Preference and Naturalness

Yuteng Zhu[1], M. Ronnier Luo[1, 2,], Sebastian Fischer[3], Peter Bodrogi[3], and Tran Quoc Khanh[3]*

[1] State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou, China
[2] School of Design, University of Leeds, Leeds, UK
[3] Laboratory of Lighting technology, Technische Universität Darmstadt, Darmstadt, Germany

Abstract

Investigation of image quality on preference and naturalness using 1- dimensional and 2- dimensional colour attributes was performed. Each colour attribute varied in two directions, and each direction had two levels, i.e. large and small. In the present study, paired comparison was employed for image preference and categorical judgement for image naturalness assessment. The aim was to evaluate the performance and effectiveness of 1-dimensional and 2-dimensional colour attributes on image quality. Furthermore, cultural difference, the relationship between image preference and naturalness, the difference between memory colours in colour patches and digital images were examined. The experimental results revealed that the effectiveness of colour attributes on image quality vary with image content.

Introduction

The topic of image quality on preference and naturalness has driven massive work in image community due to its crucial role in image reproduction and image enhancement. A. J. Calabria and M. D. Fairchild [1] investigated the influence of colour attributes on perceived image contrast and observer preference. These attributes included lightness, chroma and sharpness. It was found that image preference and perceived contrast followed the preference-percept relationship, where preference increases as a function of contrast to a maximal point then decrease. H. Ridder [2] investigated the image quality and naturalness by varying the colorfulness level of natural images. An inverted U-shaped function relation was found between image quality/naturalness and saturation. Interestingly, observers were fond of more colourful, but, somewhat unnatural images. Similar trends were concluded by Fedorovskaya *et al*. [3] on chroma variations. The work of S. Y. Choi *et al.* [4] illustrated that naturalness was the most important scale for image quality, followed by colorfulness and contrast. It inspired an image quality model based on these three perceptual appearance attributes, consisting of naturalness, contrast and sharpness.

Many researchers also made efforts on memory colours and preference colours. It has been reported that people prefer to see an object in the image to agree with the memory colour rather than the realistic colour. Therefore, memory colours greatly affects the colour preference sensation [5] [6]. H.Z. Zeng and M. R. Luo [7] studied the skin colour and then developed models and algorithms for preferred skin colour enhancement.

Previous works mainly focused on the colour attributes as lightness, chroma and contrast, which can be considered as 1-dimensional scales. These attributes, however, are not well correlated with our perceptual experience. Therefore, R. S. Berns [8] introduced three new variables, Vividness, V_{ab}^*, Depth, D_{ab}^*, and Clarity, T_{ab}^*, to extend the utility of CIELAB colour space, which combine lightness with chroma and thus can be considered as 2-dimensional colour attributes. Y. J. Cho *et al.* [9] conducted experiments to test R. S. Berns' V_{ab}^* and D_{ab}^* scales on NCS samples between British and Korean observers. The results revealed that Berns' depth and vividness had a strong positive correlation with saturation, while negative correlation with whiteness. Nevertheless, Berns' vividness scale did not well represent visual vividness of subjects. Still, the effectiveness of these new scales on the image quality remains to be examined.

The goal of this research is to contribute information relating to effectiveness of both 1- dimensional and 2- dimensional colour appearance attributes for colour image preference and naturalness enhancement. The target was approached by conducting experiments both on German and Chinese groups and generated a large-scale psychophysical data set. The effectiveness of 1-dimensional and 2- dimensional colour attributes, cultural difference, the relationship between image preference and naturalness were investigated experimentally.

Experimental

Image Rendering Method

Figure 1 shows eight original images, depicting 2 skin colours, 3 natural scenes and 3 common fruits. Each image was rendered

Figure 1. *Eight test images for this study. From left to right, they are named Asian woman (AW), Caucasian woman (CW), Blue sky (BS), Green grass (GG), Red rose (RR), Banana (BA), Green apple (GA), and Orange (OR).*

* Corresponding author: M. R. Luo, m.r.luo@leeds.ac.uk

using 7 colour attributes. The so-called 1-dimensional attributes include: chroma, hue, lightness contrast and chroma contrast, and 2-dimensional attributes include: vividness, depth and clarity

Table 1 describes the rendering methods of each attribute [10]. Depart from each original image, there generally computed large amount of images with attribute-increased or attribute-decreased globally. In this study, images used in the experiment were selected out under a condition that the new images were perceptually different from original image but still within the display colour gamut. It comes to 200 images in total, i.e. 8 testing images × (6 attributes × 4 levels + 1 original). Image-based visualization were made in Figure 2, taking Caucasian Woman as an example, to illustrate the image rendering results according to C_{ab}^*, hue, V_{ab}^* and D_{ab}^* variations. These attribute manipulations provided a wide range of image variations but each still appeared to be realistic. The rendering colour values were subjectively selected from a typical region corresponding to the prominent object in the image and their distribution was plotted in CIELAB a^*b^* and $L^*C_{ab}^*$ diagrams as shown in Figure 3.

Table 1. Summary of colour attributes rendering methods

	Colour attributes rendering method
1D	**Chroma (C_{ab}^*), Hue (h_{ab})** defined in CIELAB colour space
	Lightness contrast (S-type cubic function) $J' = -d \cdot J_{max}^{-2} \cdot J^3 + 1.5d \cdot J_{max}^{-1} \cdot J^2 + (1-0.5d) \cdot J$, where J is lightness in CIECAM02, the coefficient of adjustment d is set at small (d= 0.8) and large (d=1.6) levels.
	Chroma contrast (Power function) $C' = C^n$, where the adjustment indice n is set at small (n=1.04) and large (n=1.08) levels.
2D	**Vividness** $V_{ab}^* = \sqrt{(L_{ab}^*)^2 + (C_{ab}^*)^2}$
	Depth $D_{ab}^* = \sqrt{(100 - L_{ab}^*)^2 + (C_{ab}^*)^2}$
	Clarity $T_{ab}^* = \sqrt{(L_{ab}^* - L_b^*)^2 + (a^* - a_b^*)^2 + (b - b_b^*)^2}$, where subscript b indicates the values of the background.

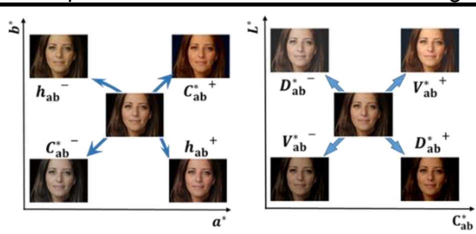

Figure 2. Illustration of 1- dimensional and 2-dimensional image rendering results of Caucasian Woman

Psychophysical Experiment

In this study, paired comparison were employed in the image preference experiment, while categorical judgement with 1-10 (from worst to best) scale was used to rate the image naturalness. This results in 2600 comparisons, i.e. $(C_{25}^2 + 25) \times 8$ and 256 assessment scores, i.e. (25+7) × 8, including repetitions for subjective judgement consistency examination.

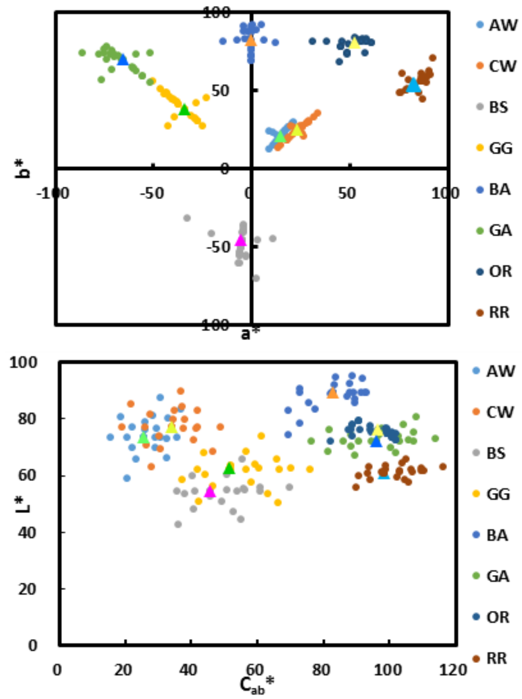

Figure 3. Distribution of rendering colour values of all images in a^*b^* and $L^*C_{ab}^*$ diagram

The two experiments were carried out on a well-calibrated EIZO CG277 LED-backlighting display in a complete dark room. The display was calibrated to 111 cd/m^2 and CCT of 6550K. The gain-offset-gamma (GOG) model was implemented to characterize the display colorimetric transformation, with 0.6 ΔE_{ab}^* unit of accuracy and 0.52 ΔE_{ab}^*unit of stability averaged from 18 neutral grey levels as test colours (0:15:255) [11].

Forty subjects with normal acuity, or corrected-to-normal colour vision participated in both experiments. They sat at approximately 60 cm in front of the display and operated through a designed Matlab GUI interface. In the first experiment (naturalness), a score between 1 and 10 was required based on the subjective judgement of the image displayed on the monitor. In the second experiment (preference), subjects were asked to give a two-alternative forced choice on the two rendering images side by side. All images were surrounded by a thin white frame and large median grey background. All images appeared in a random order. In total, 10400 preference and 2048 naturalness assessments were collected respectively.

Results and discussion

Uncertainty

The paired comparison results were firstly converted into z-scores according to Case V of Thurstone's Law as comparative judgement [12]. Naturalness results were also converted into z-score by different mathematical methods. Therefore, these two z-scores did not have the same meaning.

The observer repeatability level of preference evaluation had a mean of 70.5% overall, which means the statistical possibility that observers giving consistently the same choice on the same pair was 70.5%. However, the repeatability of red rose is the lowest, and this

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Table 2. Rank of colour attributes by STRESS value

Colour attributes	Lightness Contrast	Vividness	Clarity	Depth	Chroma	Hue	Contrast Chroma
STRESS value	26	26	27	28	29	30	31

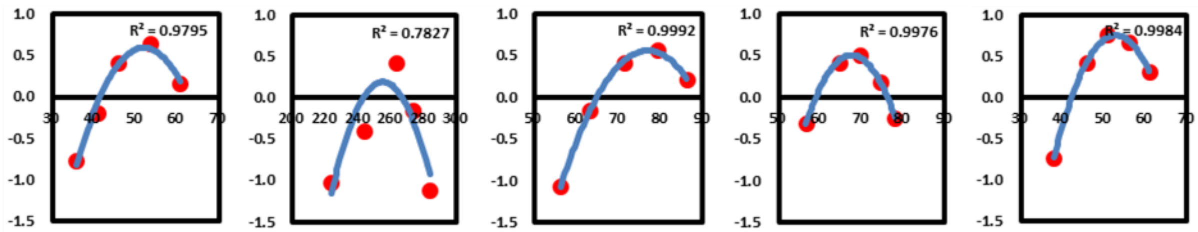

***Figure 4**. Relation between preference z-score and colour attribute variation of Blue Sky*

might be caused by its smaller colour differences between images. It turned out to be more difficult for observers to distinguish from image to image and made it more likely to give random choice.

Inter- and intra- observer uncertainty were examined for image naturalness experiment in terms of standardized residual sum of squares (STRESS) [13]. It was found that the STRESS values were 29 and 22 for inter- and intra- observer variations, respectively. Considering the observer variation on each colour attributes, it turns out that the 2-dimensional colour attributes and lightness contrast gives smaller STRESS values than those of 1-dimension as shown in Table 2. This indicates that observers agree slightly better on lightness contrast, V_{ab}^*, D_{ab}^* and T_{ab}^* in the image than on chroma contrast, C_{ab}^* and hue.

Correlation of Visual Preference and Naturalness

Table 3 lists correlation coefficient between preference and naturalness results. Overall, they agree reasonably well. Still, it is of great interest to know how preferred images and thought-to-be natural images differ from each other in colour attributes and to understand the cognitive effects therein.

Table 3. Correlation coefficient between preference and naturalness results

	Mean	AW	CW	BS	GG	RR	BA	GA	OR
Correlation Coefficient	0.75	0.76	0.73	0.72	0.76	0.79	0.78	0.90	0.68

The results show that people prefer whiter Asian woman face skin (smaller depth value), whereas they think more colorful is more natural. A lighter Caucasian woman face skin is preferred but a higher chroma contrast is considered to be more natural. Chinese observers agree well on a higher clarity blue sky for both preference and naturalness. This indicates a more vivid blue colour departing from the background. Similarly, more colourful green grass is the most preferred and thought to be natural. However, less colourful and darker red rose is preferred. Fruit preference trends are image dependent, such as a yellowish hue is the most preferred for orange and a higher lightness contrast for banana and green apple. All these findings are in great accordance with our common knowledge. The results suggest that people are in favour of more colourful images, although they argue that these images appear certain unnaturalness. This confirms what Ridder's found [2].

Attribute Performance

The relation between preference/naturalness and colour attribute variations can be described by an inverted U-shaped function consistently for all eight images, e.g. preference results of blue sky in Figure 4. The horizontal coordinate lists colour attributes one by one, and the vertical coordinate is z-score value. There appears hardly any linear tendency for the attributes investigated but inverted U-shaped function. This indicates that too large attribute variation, regardless of direction, will not improve image preference and naturalness scores.

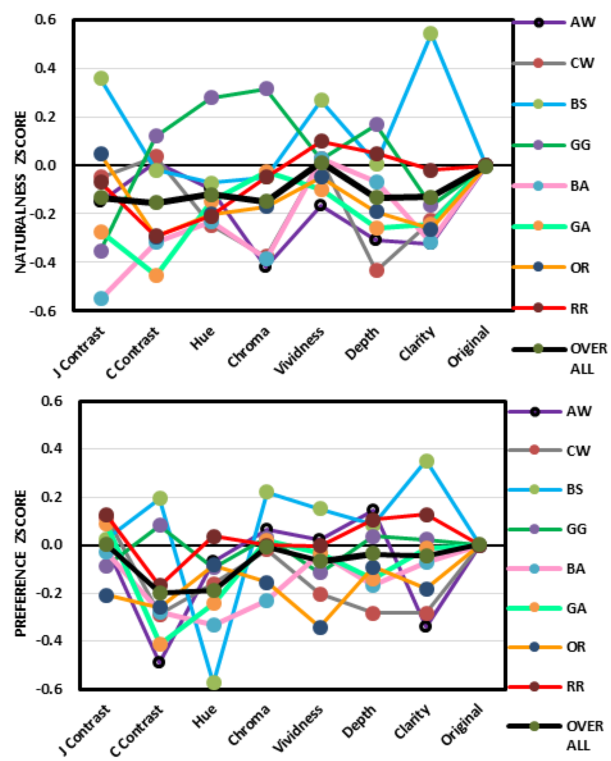

***Figure 5**. Colour attributes performance of 8 test images on naturalness (top) and preference (bottom) assessment. The legend on the right side shows the abbreviation description of image contents.*

Table 4. Details of effectiveness of colour attributes on test images

Attribute \ Image	Preference									Naturalness								
	AW	CW	BS	GG	RR	BA	GA	OR	N.	AW	CW	BS	GG	RR	BA	GA	OR	N.
Con L+	√	√				√	√		4	√	√							2
Con C+			√	√	√				3	√	√	√	√				√	5
C-	√	√					√		3							√		1
C+			√	√	√				3				√	√			√	3
Hue-					√			√	2	√			√			√		3
Hue+									0									0
V-						√			1		√		√	√	√	√	√	6
V+	√		√				√		3			√						1
D-	√							√	2									0
D+			√	√	√				3			√	√	√	√			4
T-							√		1							√		1
T+			√	√	√	√			4			√		√				2
N	4	2	5	4	5	3	4	2		3	3	4	5	4	2	4	3	

Table 5. Quantitative results of image preference and naturalness assessment

		L^*	a^*	b^*	C_{ab}^*	h_{ab}
AW	**original**	73.5	14.6	21.0	25.6	55.3
	preference	76.3	13.9	20.0	24.3	55.2
	naturalness	75.5	14.9	22.2	26.8	56.1
CW	**original**	77.0	23.2	24.7	33.9	46.9
	preference	78.2	21.7	23.0	31.6	46.7
	naturalness	75.9	23.3	24.8	34.1	46.8
BS	**original**	54.5	-5.2	-45.4	45.7	263.4
	preference	55.0	-5.4	-53.6	53.8	264.2
	naturalness	55.5	-5.5	-47.8	48.2	263.5
GG	**original**	62.4	-34.3	38.2	51.6	131.0
	preference	61.8	-38.0	42.4	56.9	131.9
	naturalness	61.8	-33.9	41.6	53.6	129.2
RR	**original**	61.1	82.5	53.3	98.4	32.7
	preference	61.5	85.8	55.9	102.4	33.1
	naturalness	59.5	83.6	54.9	100.0	33.3
BA	**original**	89.3	-0.6	82.8	82.8	90.5
	preference	89.3	-1.2	82.7	82.7	90.8
	naturalness	83.3	-0.4	79.7	79.8	90.3
GA	**original**	72.0	-65. 7	70.0	96.0	133.2
	preference	72.8	-63.9	68.1	93.4	133.2
	naturalness	70.8	-61.3	67.8	91.4	132.1
OR	**original**	76.1	52.7	80.6	96.4	57.0
	preference	75.3	54.4	81.4	97.9	56.3
	naturalness	76.7	49.2	80.7	94.5	58.6

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Figure 5 plots relative z-scores against naturalness (top) and preference (bottom) of 8 images on 7 different attributes via different transformation methods, whereas the relative z-scores were calculated as the z-score difference between a rendered image and the original image. That is to say, if relative z-score is above zero, then the image improves in image quality. For better visibility, the data points of the same image on different colour attributes were filled with the same colour and linked together by straight lines. The performance of specific colour attribute acting on different images can be read vertically, while different attributes on the same image can be attained from the same colour line left to right. The higher z-score it is, the better it acts on the image. Finally, the black line represents the averaging results of the underlying attributes from all 8 test images.

From Figure 5, it can be seen that the results differ from image to image. This demonstrates that the image enhancement method should consider the image content rather than generic and universal manipulation for all cases. For instance, chroma contrast modification can increase the preference level for outdoor scenes, e.g. blue sky and green sky, but poorer results for the other images. Colour attributes manipulations can improves image preference greatly in many cases but give less chance for image naturalness.

Table 4 lists the rendered images enhanced (with tick √) by different colour attributes together with variant directions. The numbers in last row are the sum of colour attributes that can be applied to make an effective improvement on image preference/naturalness. The numbers in the column give the number of images that could be augmented in image preference/naturalness property under certain attribute manipulation. There seems to be no dominant attribute among 1-dimensional and 2-dimensional attributes on the on all image contents.

Overall, two image quality features, preference and naturalness, are highly correlated in measure of colour attribute as shown in Table 3, but people realize that a less vividness and a higher chroma contrast is more natural. As for specific object, a less colourful and a whiter (less depth) skin colour is more preferred, especially for Asian woman. People like more colorful and larger chroma contrast of objects like blue sky, green grass, red rose, of which scenes are under high dynamic range illuminating.

Given that the performance of colour attributes varies with image content, it motivates us to determine the colorimetric values for the most preferred/ natural images. Therefore, the representable L^*, a^*, b^*, C_{ab}^* and h_{ab} colour values are calculated by weighting the top preferred/natural rendered images values by z-score as shown in Table 5. The formula is represented as below:

$$L' = \sum_{i=1}^{k} L_i * (z_i / \sum_{i=1}^{k} z_i) \qquad (1)$$

where i refers the top i^{th} image, k = 3 ~ 5 according to image content and z-score. Similarly, a^* and b^* values are calculated by the same way. Table 5 lists quantitative object colour values of original, mosy preferred and natural images and these can be applied to enhance colour reproduction and image quality from subjective perspective.

Cultural Difference

Apart from the work described above, experiments that investigated the cultural difference on image preference and naturalness were also conducted in Germany and in China. In this stage, only 1-dimensional colour attributes (lightness contrast, chroma contrast, chroma and hue) were evaluated. Data analysis was based on 34 German and 35 Chinese participants.

Table 6. Comparison of German and Chinese results

Image content	Correlation Coefficient (R)		Colour Difference (DE)	
	Preference	Naturalness	Preference	Naturalness
AW	0.9	0.94	2.9	0.7
CW	0.93	0.89	1.8	1.4
BS	0.82	0.75	8.1	6.8
GG	0.32	0.91	10.4	3
RR	0.96	0.67	0.8	2.4
BA	0.86	0.82	3.6	4.3
OR	0.85	0.83	5.1	6.3
GA	0.92	0.75	5.3	6.3
Mean	0.82	0.82	4.8	3.9

From Table 6, it can be seen that the average correlation coefficient of two cultural groups reaches 0.82 both for preference and naturalness judgement. From looking into the most preferred/natural images, it was found that Chinese subjects prefer more colorful images than German subjects, such as blue sky, green grass, and orange. Moreover, Chinese also consider the more colourful images to be more natural.

Quantitative CIELAB values were calculated according to Eq.1 and comparison was made between German and Chinese results. Average colour differences were 4.8 ΔE_{ab}^* for preference and 3.9 ΔE_{ab}^* for naturalness, but the differences on blue sky and green grass were significant. This reflects the cultural or regional difference on natural scenes.

Comparison of Image Assessment and Memory Colour Patch Results

Investigation of memory colour of familiar objects using colour patches [14] was studied under similar viewing condition and display parameters. Figure 6 shows results of image preference and image naturalness against colour patch in CIELAB a^*b^* diagram. It can be seen that hue is the most consistent across different measures, i.e. hue differences are less than 10° . But there is an exception, blue sky, of which the memory colour is more purple-bluish than image results. This difference be caused by the selected blue sky image, which limits the colour change comparing to vast natural scenes about blue sky. Overall, image results appear lighter than memory color, whereas chroma varies according to different object studied.

Conclusions

In the current work, the effectiveness of 1- dimensional and 2-dimensional colour appearance attributes for image quality on preference and naturalness by subjective evaluation was investigated. The influence of colour attribute variations on image quality can be described by quadratic function regardless of attribute dimensions and image content difference. However, colour attribute performance on image preference and naturalness vary prominently

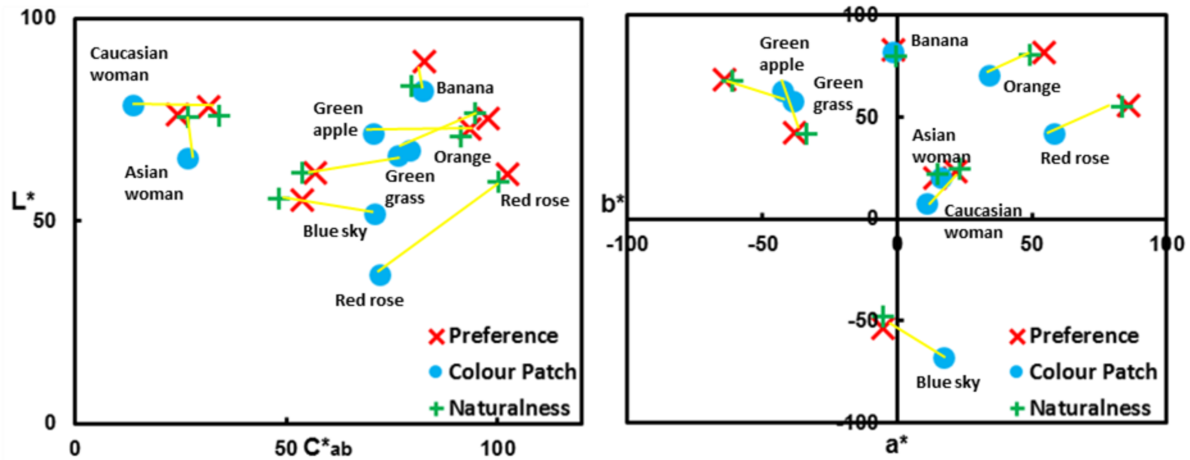

Figure 6. *Comparison of image preference, image naturalness and memory colour results. Left: Cab*L* diagram, right: a*b* diagram. In both figures, blue circles represent colour patch results, red crosses represent image preference results, and green pluses represent image naturalness results. There exists yellow lines that link different results of the same objects together.*

with image content. Overall, vividness and chroma contrast are the most important attributes for image naturalness, while clarity and lightness contrast for image preference.

Subjects are in favour of whiter and lighter skin colours, higher clarity blue sky, more colourful green grass and red rose, more yellowish orange, larger chroma contrast banana and green apple. For outdoor scenes, such as blue sky and green grass, larger chroma contrast and greater colorfulness images are preferred. As for naturalness, less vivid fruits, higher chroma contrast skins, blue sky, and green grass are considered to be more natural. The results suggest that image quality enhancement though colour attributes should consider the image content for higher effectiveness.

Moreover, quantitative CIELAB values of preference and naturalness results for eight common objects were obtained, which could be employed for colour reproduction and image enhancement.

The main limitation of our approach is the global clolour attribute manipulation instead of region of interest in the image. This will cause unnatural change on the image background or surroundings. Another issue is the selection of original image of fruits, which should be more natural originally and makes results more reliable. These are the improvements we plan to focus on.

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Author Biography

Yuteng Zhu received her BS in Optical engineering from Zhejiang University (2010) and currently she is pursuing Master degree in Colour and Imaging Science under supervision of Prof. M.R. Luo. Her work has focused on Memory colour and Image enhancement.

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