MODELING IMAGE QUALITY ATTRIBUTES BASED ON IMAGE PARAMETERS FOR MOBILE DISPLAYS

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Keywords: image quality, mobile display, psychophysical evaluation

ABSTRACT

High image quality (IQ) on the widely used mobile displays is extremely desirable for viewing static and moving images. This study focuses on modeling the perceived IQ considering all types of images for mobile displays. Large-scale psychophysical experiments via categorical judgment method were carried out on mobile displays of different physical sizes under lighting conditions of two illuminance levels, in order to visually assess seven perceptual attributes, i.e. naturalness, colorfulness, brightness, contrast, sharpness, clearness, and overall IQ. The results reveal that clearness and naturalness are two principal attributes to predict overall IQ for natural scene images, whereas clearness and colorfulness are key attributes for other types of images (games, maps, and internet). Moreover, the influences of display technology, display size and lighting level have been analyzed as well. Based on the preliminary models of overall IQ with these selected attributes, further expressions to predict individual IQ attributes could be modeled by combining some image and display parameters.

INTRODUCTION

Nowadays, with the increased use of mobile devices such as smartphones, game consoles, and tablet computers, high image quality (IQ) has become extraordinarily desirable for these mobile displays. Therefore, determining the critical factors of overall IQ is helpful to achieve excellent image visual effects on mobile displays. This study focuses on modeling the perceptual IQ attributes of mobile displays, aiming to express the overall IQ by some image and display parameters (image lightness, colorfulness, display size, etc), as well as the lighting conditions [1].

The general application of mobile displays is different from that of desktop displays or TVs, i.e. they are freely applied in a wide range of lighting conditions because of their portability, what's more, images shown on mobile displays involve several application types such as natural scenes, games, maps, internet, and so on [2]. Considering their specificity in practice, the test images in the visual evaluation included both natural scenes and other application types of games, maps, and internet. Moreover, to investigate the influences of display size and lighting level, the experiments were carried out on mobile displays of very different physical sizes, under the dark surround and the 500 lx lighting condition. Seven perceptual IQ attributes were evaluated via psychophysical experiments to reveal the critical factors contributing towards the overall IQ significantly. Thus, based on the key attributes selected to predict overall IQ, the comprehensive IQ model linked to image parameters could be established for different application types of images.

METHOD

Devices and images

The whole experiments were carried out on two smartphones and two tablet computers, in order to take into account the effects of display technology and display size on perceptual IQ attributes for mobile displays. Their physical parameters are listed in Table 1.

Table 1: The basic physical parameters of the tested mobile displays

Parameters	P1	P2	T1	T2
Size (inch)	3.5	4	9.7	10.1
Display material	IPS	AMOLED	IPS	TFT
Resolution	640 × 960	480 × 800	1536 × 2048	800 × 1280
PPI: pixel per inch	326	233	264	149
Peak white luminance (cd/m^2)	539	331	242	315
CCT: correlated color temperature (K)	7658	9407	6595	7023
Gamut ratio to sRGB in CIE1976UCS	0.624	1.362	1.090	0.587

IPS: in-plane switching. AMOLED: active matrix organic light emitting diode. TFT: thin film transistor.

The visual assessments were conducted under the dark surround (for all the 4 displays) and ambient lighting condition with the illuminance of 500 lx (for P1 and T1) to simulate the office lighting, respectively, resulting in 6 experimental phases of Dark-P1, Dark-P2, Dark-T1, Dark-T2, 500 lx-P1, and 500 lx-T1. The model of the lighting tube was OSRAM DULUX-L 55W/954 with the CCT of approximately 5000 K.

The test images covered a considerable scope of common image contents for mobile displays, which not only included some familiar memory colors such as skin, green grass, and blue sky, but also considered other specific application types such as internet, games, and maps as well. Figure 1 illustrates several typical examples of the selected images from different image types.

Figure 1. Some typical samples of the original test images in the IQ experiments

The images shown on the two smartphone displays were resized to the same size of 5 cm × 7.5 cm, while for the two tablet computers, the images were set as 13.6 cm × 19.7 cm. The original images were manipulated by changing image appearance parameters, including three color appearance parameters of hue h, chroma C, lightness L*, along with the spatial frequency [3]. For each pixel, its L*, C, h values were calculated from the digital inputs, on which various manipulation methods were performed, including 3 linear functions to change lightness, 3 linear functions for chroma manipulation, 4 shifts of hue, 4 kinds of Gaussian function for spatial frequency. Then, these modulated L*', C', h' values were rendered to newly manipulated image versions. In addition, 3 manipulations for resolution were obtained by 'bicubic' method directly from digital inputs. Therefrom, a realistic range of variations for each original image was generated.

Psychophysical procedure

The psychophysical experiments were conducted by a panel of 10 observers (5 male and 5 female) with normal color vision. The viewing distance was about 30 cm, and the observers focused their attentions on the panels perpendicularly. Seven perceptual IQ attributes previously proved to be important were chosen, i.e. naturalness, colorfulness, brightness, contrast, sharpness, clearness, and overall IQ [4, 5]. The categorical judgment method was adopted, in which the observers judged the individual IQ attribute with a memorized reference. A nine-point numerical category scale ranging from 1 to 9 was used to describe the perceptual feelings in grades.

RESULTS AND DISCUSSION

Influences of display type and lighting condition

The raw data from categorical judgment is in term of category grades. To deeply analyze the experimental results, these categorical grades judged by the 10 observers were converted to an interval scale value for each evaluated image version by adopting Case V of Thurstone's law on comparative judgment [6]. The mean scale values of the 7 perceptual attributes for each experimental phase are plotted in Figure 2.

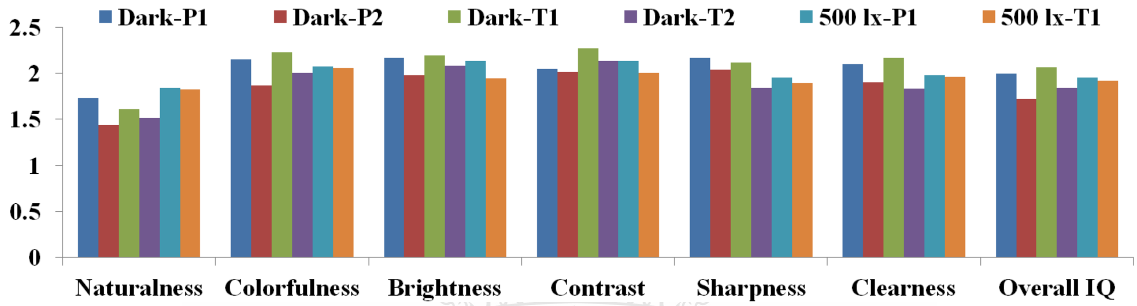

Figure 2. The mean scale values of the 7 perceptual attributes for the 6 experimental phases

For the influences of display technology, as clearly seen from Figure 2, the IPS (P1 and T1) performs better than AMOLED (P2) or TFT (T2) on all the 7 attributes, which may be due to its advantages of high PPI and suitable CCT. As for the impacts of lighting condition, the 500 lx illumination mildly reduces the scores of colorfulness, brightness, sharpness and clearness, but brings about an increase on naturalness, which indicates that the dark surround could accentuate some color appearance attributes such as colorfulness and brightness, and make images be striking. Also depicted in Figure 2, scores of the two IPS displays of different sizes are almost on a par, though T1 performs better on contrast and colorfulness, while P1 gets higher score on naturalness, which implies that it is other factors rather than just size to introduce these differences of their performances.

Modeling overall IQ

For all the 6 phases, the Pearson correlation coefficients between the overall IQ and its six constituent attributes were calculated to determine the principal attributes to significantly influence the overall IQ. The results are listed in Table 2.

Table 2: The Pearson correlation coefficients between overall IQ and its 6 constituent attributes, along with the prediction accuracy of two image types, for the 6 phases

Pearson correlation coefficients		Dark-P1	Dark-P2	Dark-T1	Dark-T2	500 lx-P1	500 lx-T1
Correlation between overall IQ and its constituent attributes	Naturalness	0.795	0.704	0.783	0.698	0.811	0.761
	Colorfulness	0.535	0.413	0.508	0.561	0.527	0.511
	Brightness	0.296	0.218	0.269	0.191	-0.008	0.313
	Contrast	0.504	0.399	0.571	0.509	0.400	0.602
	Sharpness	0.557	0.527	0.754	0.730	0.725	0.767
	Clearness	0.768	0.809	0.803	0.877	0.857	0.814
Prediction accuracy	Natural scene images	0.934	0.930	0.931	0.938	0.948	0.935
	Other application images	0.877	0.879	0.881	0.923	0.926	0.916

Oral paper

It can be seen that naturalness and clearness exhibit high preponderance on impacting the overall IQ for all the 6 phases, while sharpness, colorfulness, and contrast show some influences in a way. Yet as our previous study pointed out, contrast is not an independent variable but a compound attribute, which is influenced by some factors simultaneously, and clearness is more suitable than sharpness to represent the overall IQ, due to the discordance between sharpness and overall IQ in the over sharpened situation [7]. Consequently, the overall IQ for natural scene images could be predicted well by adopting its two constituent attributes, clearness and naturalness. Whereas for predicting the overall IQ of other application images, clearness should be chosen as an indispensable attribute, and colorfulness is considered as a complementary element. The last two rows in Table 2 list the prediction accuracy of the overall IQ models by its two selected attributes (Pearson correlation coefficients between the predicted overall IQ values and the visually evaluated overall IQ results) for natural scene images and other application images respectively, which verifies these above conclusions.

Hence, to create empirical models capable of predicting the overall IQ from image parameters, modeling the overall IQ by its two key constituent attributes is just the first step, the next step is to build the mathematical links from image parameters towards the perceptual attributes of clearness, naturalness, and colorfulness. Therefore, our further research will mainly focus on modeling these above individual attributes, then an empirical procedure will be developed to predict the perceived image quality linked to image parameters presented on displays.

CONCLUSION

Seven image quality attributes were visually evaluated for four mobile displays under two lighting conditions using test images from different application types. Their scale values of different experimental phases were compared to investigate the influences of display technology, display size, and lighting condition. Moreover, the calculation of Pearson correlation coefficients reveals the key attributes to impact the overall IQ obviously for natural scene images and other application images of mobile displays, respectively. To achieve the ultimate goal of modeling the perceptual attributes from image parameters under various lighting conditions, the future research will focus on developing mathematical expressions of perceptual attributes from image parameters. This study may provide helpful suggestions for display manufactories to develop mobile displays with excellent image and video effects.

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