Optik 125 (2014) 2554–2559

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Impacts of appearance parameters on perceived image quality for mobile-phone displays

Rui Gong, Haisong Xu*

State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou 310027, China

ARTICLE INFO

Article history:
Received 29 May 2013
Accepted 25 October 2013

Keywords:
Image quality
Psychophysical evaluation
Mobile-phone display
In-plane switching (IPS)
Active matrix organic light emitting diode (AMOLED)

ABSTRACT

In order to investigate the perceived image quality (IQ) influenced by different image appearance parameters, a psychophysical experiment was carried out on two mobile-phone displays of different technologies, the in-plane switching (IPS) and the active matrix organic light emitting diode (AMOLED). The test images were generated within a wide range of variations by applying various manipulation methods, involving changes in several kinds of image appearance parameters, i.e. lightness, chroma, hue, and spatial frequency. The perceived attributes of naturalness, colourfulness, brightness, contrast, sharpness, clearness, preference, and overall IQ were visually assessed via categorical judgement method for several application types of test images. The impacts of the manipulation methods on individual attributes have been deeply discussed based on the interrelationships of these attributes, which reveal that the significant parameters towards better overall IQ for mobile-phone displays include high lightness, suitable chroma and lightness frequency distribution, and impartial hue, accordingly better image quality will be accomplished after all these parameters have been optimised at the same time. The achievements of this study would provide constructive instructions on achieving excellent display effects for researchers and manufactories of mobile-phone displays.

1. Introduction

Excellent image display effect has become extremely desirable for the widely used mobile-phones. Therefore, some display technologies have been developed to achieve high image quality (IQ) on these small-sized displays for viewing static and moving images.

There have been many research activities on the IQ evaluation of displays, and a major approach among those is to develop models that are capable of predicting the perceived quality of images [1]. Most of these studies concentrated on the correlations of different IQ attributes, as well as finding the impacts of individual IQ attributes on the overall IQ [2–4]. Those studies were mostly carried out on relatively large size displays such as desktop monitors or TVs, and they usually employed pictures of natural scenes as test images. However, the image quality perception of mobile-phones is different from that of desktop displays or TVs, because the images shown on mobile-phone displays have smaller size, and they include different application types of games, GPS, e-books, and so on. To achieve the ultimate goal of creating empirical models that can mathematically predict the perceptual IQ attributes for mobile-phone displays, this study mainly focuses on revealing the impacts of different image appearance parameters on the IQ attributes using various application types of test images.

In our previous work [5], several IQ attributes were visually assessed on mobile-phone displays with two different technologies, which reveals that both the in-plane switching (IPS) technology [6] and the active matrix organic light emitting diode (AMOLED) technology [7] have their individual advantages and weak points on image display effects. Based on the consideration of providing a wide and realistic range of image variations for visual assessments, a typical psychophysical experiment was carried out on an IPS display and an AMOLED panel, respectively, in this study.

In the visual evaluation, 8 perceived IQ attributes that had previously been proved important were chosen, i.e. naturalness, colourfulness, brightness, contrast, sharpness, clearness, preference, and overall IQ [8,9]. All the test images were manipulated by changing different image appearance parameters, including the three colour appearance parameters of hue, chroma, lightness, along with spatial frequency, which is an important parameter for complex images. Thus the correlations between these parameters and each perceived IQ attributes were deeply discussed, aiming to provide helpful suggestions for improving the quality of the input images by optimising all these parameters. Moreover, the interrelationships among various IQ attributes were analysed, as well as the critical factors to influence the overall IQ of mobile-phone displays, which would establish an important foundation for the comprehensive IQ modelling in the future work.

* Corresponding author. Fax: +86 571 87952652.
E-mail addresses: gr2211@126.com (R. Gong), chsxu@zju.edu.cn (H. Xu).

0030-4026/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.ijleo.2013.10.092

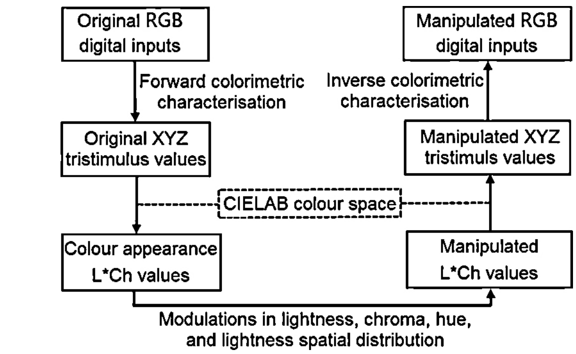

Fig. 1. The workflow of the manipulation process for generating test images.

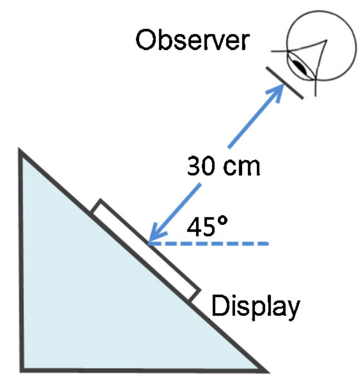

Fig. 2. The viewing geometry in the visual experiment.

2. Experimental

2.1. Image preparation

The visual experiment was conducted on two mobile-phone displays with two prevailing technologies, IPS and AMOLED. Table 1 summarises the physical parameters of the two displays and all the test images. To cover a considerable scope of common image contents, 20 test images were selected from several specific application categories for mobile-phone displays, which not only included some familiar memory colours such as skin, green grass, and blue sky, but also considered other application types like internet, games, and maps as well. There were 6 images to test typical memory colours, 2 images containing sharp lines and edges, and 4 night scene images showing high contrast components in their lightness distributions. Additionally, test images from other specific application types were adopted, including 2 game scene images with bright and clear graphic contents, and another 2 game scene images containing obvious contrast grades and fine details, along with 2 maps with sharp lines and a certain amount of characters, and 2 internet images that lay particular emphasis on characters.

These images were resized to ensure their same physical size of 5 cm × 7.5 cm. To investigate the influences of image appearance parameters, a wide range of variation is necessary. Hence all the test images were rendered using various manipulations, involving changes in the appearance parameters of lightness, chroma, hue, and spatial frequency. For each pixel, the modulation process for generating its new digital input RGB is demonstrated in Fig. 1, where the accuracies of forward characterisation were 0.98 and 1.92 ΔE^*_{ab} units for the IPS and AMOLED displays, respectively [10–12], and the reverse characterisation yielded a colour difference of 1.45 ΔE^*_{ab} units for IPS, and 2.36 ΔE^*_{ab} units for the AMOLED panel.

Table 2 lists the functions and parameters of all the types of manipulations. In CIELAB colour space [12], different manipulations were implemented in terms of lightness L^*, chroma C, hue angle h, and lightness spatial distribution. Three linear manipulations in L^* channel were performed, denoted as L60 (60% of original lightness), L80, and L120, corresponding to r values of 0.6, 0.8, and 1.2, respectively. Reductions and increases in lightness contrast were simulated using the sigmoid and inverse sigmoid functions in L^*. The lightness manipulation by sigmoid function, denoted as LS method, could reduce the lightness for dark areas but increase the lightness of bright areas for the original image, and the lightness manipulation by inverse sigmoid function, LIS method, would provide an opposite effect. Similarly to the lightness linear manipulations, the chroma C used a linear function with three different slopes of 0.6, 0.8, and 1.2, corresponding to the methods of C60 (60% of original chroma), C80, and C120, respectively. In the hue domain, shifting hue angle in the increase direction and the decrease direction resulted in four methods denoted as HD15 (decreasing hue angle by 15°), HD30, HI15 (increasing hue angle by 15°), and HI30, respectively.

Two kinds of methods were applied to manipulate the spatial frequency of the original image. One method was applied in CIELAB colour space that only modulated the lightness frequency domain without changing hue and chroma [13], resulting in a sharpness change of an image. The cut-off frequency parameter k equals 1/3, 1/5, 1/7, or 1/11 for methods S1/3, S1/5, S1/7, and S1/11, respectively. Since being multiplied by the parameter k makes the cut-off frequency smaller, the image becomes sharper with the increase of k by emphasising the edge areas in an image. Another type of spatial frequency manipulation was to change the pixel resolution of an image, which affected the ability of an observer to distinguish and recognise its fine spatial details. This method was not based on CIELAB colour space, and the test images were rendered to simulate the situations of lower resolutions using the bicubic resampling technique, equivalently regarding 2 × 2, 3 × 3, and 4 × 4 pixels as one 1 × 1 pixel (marked as R2, R3, and R4), respectively. Since the two panels have different pixel per inch (PPI) parameters, the resolution manipulations produce deficiencies on image details to varying degrees. Finally, 20 derivative versions of test images were generated for each original image, resulting in 400 test images (20 manipulation versions × 20 original images) in total for the visual evaluation.

2.2. Psychophysical procedure

The psychophysical experiment was conducted by a panel of 10 observers (5 male and 5 female, ages of 23–30 years old) with normal colour vision in a dark room, among whom 5 observers repeated part of the evaluation to investigate the intra-observer variability. The viewing angle was 14.25° × 9.53° at a distance of 30 cm, and the observers focused their attentions on the panels perpendicularly, as demonstrated in Fig. 2.

In the whole experiment, 16 evaluation sessions (8 perceptual attributes × 2 mobile-phone displays) were carried out. Each session lasted approximately 15–20 min for individual observer, in which the 20 manipulated versions for each test image were shown on one display in a random sequence until all the 20 test images were evaluated. Based on the psychophysical method of categorical judgement, the observer made his/her judgement on the individual IQ attribute with a memorised reference [1]. A 9-point numerical category scale with a range of 1–9 was employed to describe the perceptual feelings in grades.

The evaluated attributes include naturalness, colourfulness, brightness, contrast, sharpness, clearness, preference, and overall IQ. The definitions of these attributes were presented to the observers both in English and in Chinese. Naturalness is defined