Evaluation of colour appearances displaying on smartphones

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ABSTRACT

Despite of the limited size and capacity of a mobile phone, the urge to apply it to meet quotidian needs has never been unencumbered due to its appealing appearance, versatility, and readiness, such as viewing/taking pictures and shopping online. While a smartphone can act as a mini-computer, it does not always offer the same functionality as a desktop computer does. For example, the RGB values on a smartphone normally cannot be modified nor can white balance be checked. As a result, performing online shopping using a mobile phone can be tricky, especially when buying colour sensitive items. Therefore, this research takes an initiative to investigate the variations of colours for a number of smartphones while making an effort to predict their colour appearance using CIECAM02, benefiting both phone users and makers. The paper studies models of Apple iPhone5, LG Nexus 4, Samsung, and Huawei, by capitalising on comparisons with a CRT colour monitor that has been calibrated under the illuminant of D65, to be in keeping with the usual way of viewing online colours. As expected, all the phones present more colourful images than a CRT does.

1. INTRODUCTION

A smartphone is a mobile phone with more advanced computing capability and connectivity than basic feature phones, offering functionalities of typically personal assistance, media player, digital camera, and a GPS navigation unit in addition to the basic calling/receiving facilities. At present, the global smartphone audience has reached 1 billion consumers [eMarkter] and expects to arrive at 1.75 billion by the end of 2014. As such, mobile sales are not only focusing heavily on smartphones, but also on the more affordable option of feature phones that do not have an operating system. As a result, mobile penetration has surpassed 100% in many regions of the world, including North America, Western Europe, Central and South America, Central and Eastern Europe, and the Middle East [WeAreSocial]. Among those smartphone users, about half of them go online by using the phone regularly. Table 1 lists the top 10 most popular smartphones on the market.

Table 1. Top 10 smartphone list as of May 2014 [Counter].

Rank	Brand	Model
1	Apple	iPhone 5s
2	Samsung	Galaxy S5
3	Samsung	Galaxy S4
4	Samsung	Note 3

5	Apple	iPhone 5c
6	Apple	iPhone 4S
7	Xiaomi	MI3
8	Samsung	Galaxy S4 mini
9	Xiaomi	Hongmi Redrice
10	Samsung	Galaxy Grand 2

One of the unexpected by-products of smartphones remains in the field of digital photography. It appears that more photos are taken by using Smartphones than normal cameras. For example, the Apple iPhone 5 is currently the most popular 'camera' on Flickr.com [Flickr]. As a direct result, large amount of money are being investigated by mobile developers to create photo apps in an attempt to satisfy the demands of 'serious' camera phone photographers.

While using smartphone to perform everyday activities, colour remains one of the key factors, in particular in online shopping. Similar to any other digital device, a phone represents a digital image in a RGB colour space. Therefore when an image is to be processed, it is usually firstly converted into the colour space of, say, hue, lightness and colourfulness. In this way, the dependency of RGB space on hardware devices can be circumvented, i.e., a colour in one device usually does not appear nor measure the same as the one in another device even with the same RGB values in both devices. This is because the range of R, G, or B values are manually set to be the same (such as [0, 255] for an 8-bit computer) for all devices regardless their physical measurements. On the other hand, hue, colourfulness and lightness, space agrees more with human vision theories. To further improve the fitness between users' perception and retrieved results, CIE has recommended a colour appearance model CIECAM02 to predict colours appear on any media under a number of viewing conditions [Moroney]. Stemmed from Hunt's early colour vision model [Luo (a) 1993, Luo (b) 1993] employing a simplified theory of colour vision for chromatic adaptation together with a uniformed colour space, CIECAM02 can predict the change of colour appearance as accurately as an average observer under a number of given viewing conditions. In particular, the way that the model describes a colour is reminiscent of subjective psychophysical terms, i.e., hue, colourfulness, chroma, brightness and lightness.

To begin with, CIECAM02 takes into account of measured physical parameters of viewing conditions, including tristimulus values (X, Y, and Z) of a stimulus, its background, its surround, the adapting stimulus, the luminance level, and other factors such as cognitive discounting of the illuminant. The output of the colour appearance model predicts mathematical correlates of perceptual attributes.

With regard to the representation of the colour appearance of an image, in this investigation, the perceptual colour attributes of lightness (J), colourfulness (M) and hue (H) are employed.

2. METHOD

Thirty test colours are randomly selected from the Munsell colour book while making an effort to cover as much CIE 1931 colour space as possible. Psychophysical experiments are then carried out on both 19" CRT colour monitor with its illuminant calibrated to D65 and mobile phones. As illustrated in Figure 1, each test colour is placed at a centre against a grey background (with 20% of luminance of reference white) and surrounded by the reference white, reference colourfulness and surrounding colours. The test field in the centre subtends a visual angle of 2^o at a viewing distance of ~60cm. Ten subjects with normal colour vision are selected to conduct the experiments using the technique of magnitude estimation which they have been trained in advance to apply skilfully. Specifically, for each test colour, each subject is asked to estimate its appearance in terms of lightness, colourfulness and hue contents verbally that are then recorded by an operator sitting nearby.

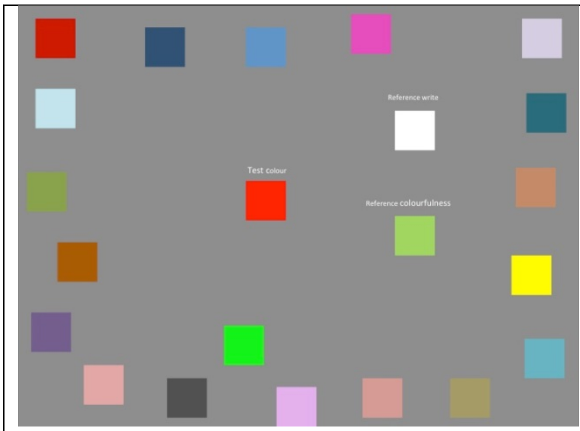

Figure 1. The paradigm of the experimental pattern.

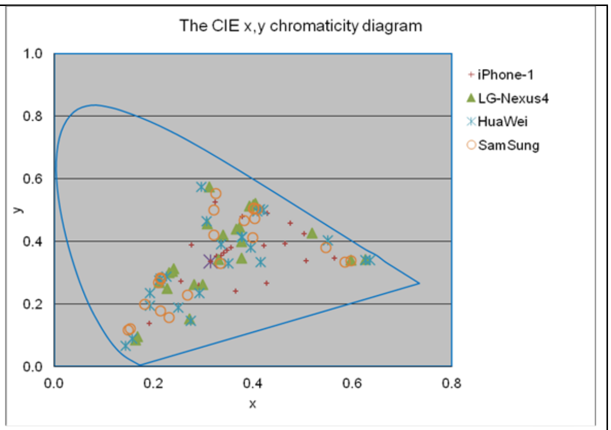

*Figure 2. The x, y data of the thirty sample colours plotted on the CIE xy Chromaticity diagram for the four phones to be studied in this research. The big * refers to the reference white.*

In addition, each colour on each phone has been measured using a colour meter CS-100A, simulating subjects' viewing position. Specifically, the reference white, reference colourfulness, and background are measured at least 3 times, e.g., at the beginning, the middle and the end of the colour sample sequence, to check the repeatability of the phone. In total, 6 phones, including three iPhone5, one Huawei, one SamSung, and one LG Nexus4, are measured and estimated. The same work is also performed on the CRT monitor, Philips Brilliance 201B. The measured data are presented in a CIE xy Chromaticity diagram as illustrated in Figure 2.

3. RESULTS AND DISCUSSION

3.1 iPhone

Three handsets of iPhone 5 are investigated in this paper. Figure 2 compares the subjects' estimation results between CRT and iPhone 5 where correlation coefficient (r) values are 0.76, 0.62 and 0.96 respectively for Lightness, colourfulness, and hue estimations.

For lightness, the estimation on mobile iphones tends to be 16% more than that on CRT mornitors, whereas 11% increase of colourfulness for mobile phones is evidenced. In Figure 4, a hue-colourfulness plot is presented, where small circles (o) represent the colours from CRT and big square (□) from iPhone5.

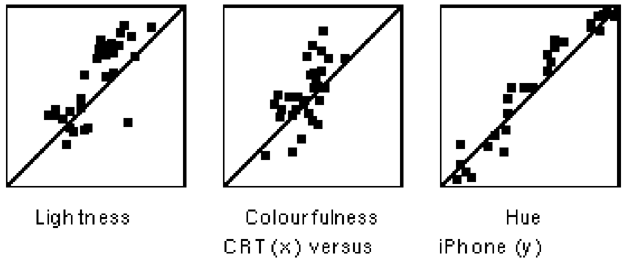

Figure 3. Comparison of subjective estimations of the thirty samples for CRT (x-axis) and iPhone 5 (y-axis).

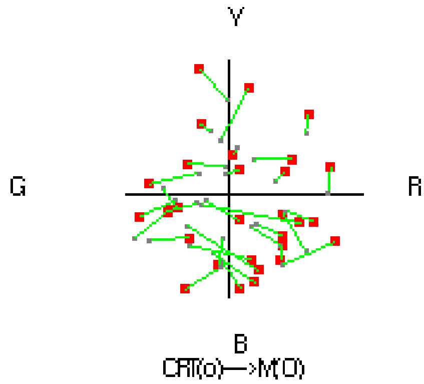

Figure 4. Subjects' estimation for the same group of colours on both CRT and Iphone5. Small circle(o) refers to the estimation for CRT whereas big solid square (▪) on Iphone.

3.2 Modelling of Iphone appearance using CIECAM02

Since the colour appearance model CIECAM02 is developed for the media of CRT, refection and transparency, it may not be well equipped to predict smartphones. After the setting of environmental parameters to 'dim' condition where F =0.9, c = 0.59, and Nc=0.90 to compensate lightness differences between CRT and iPhone, the comparison results are given in Figure 6 for the three phones, where colourfulness is adjusted according to Eq. (1).

$$Colourfulness\_smartphone = 1.8 * Colourfulness\_CIECAM02 \quad (1)$$

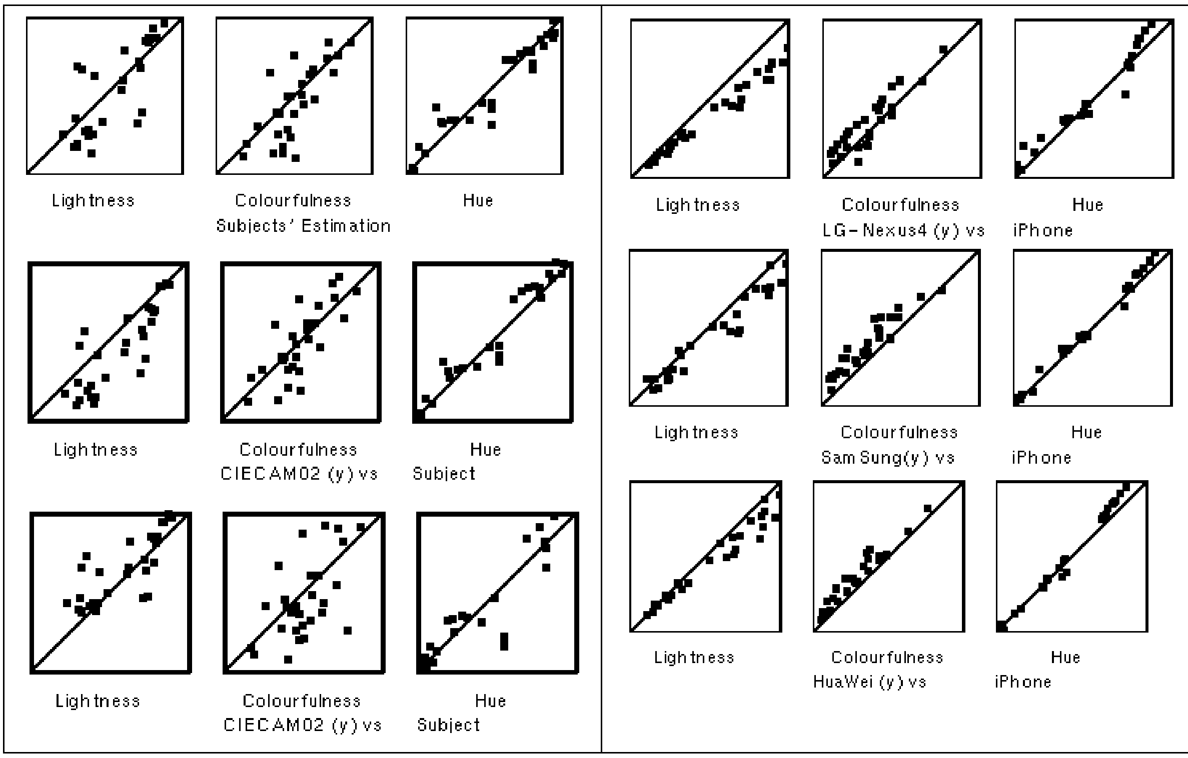

Figure 6. Comparison of CIECAM02 predictions with subjects estimations.

Figure 7. Comparison of iPhone (x-axis) with phones of LG-Nexus4 (top), Samsung (middle) and Huawei (bottom) by modified

It can be seen that after the correction using Eq. (1), the modified CIECAM02 can predict smartphones accurately.

3.3 Comparison with other smart phones

After the modelling of iphones using CIECAM02, a number of other smartphones are evaluated as well, including, a LG-Nexus4, SamSung, and HuaWei. Figure 7 presents the comparison results by the calculations using CIECAM02 for all the phones, whereas Figures 8 demonstrates a colour checker depicted on these phones.

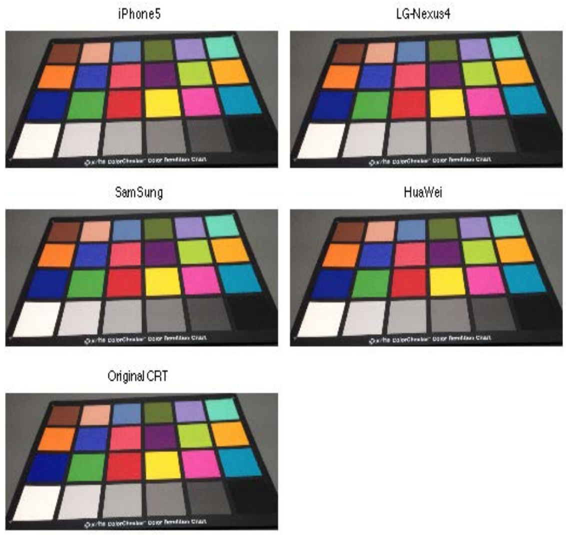

Figure 8. Colour checker depicted using four phones and CRT

When comparing with the other smartphones, in terms of hue, all three phones tends to be more reddish for purplish colours than those displayed on an iPhone, whereas the rest maintains near the same. With regard to lightness, for lighter colours, all three phones unanimously appear darker than on iPhones with LG-Nexus being the darkest with 25% darker, whereas 18% and 16% darker are evidenced for HuaWei and SamSung respectively. However, the opposite phenomenon occurs when it comes to the representation of colourfulness. All three phones of LG-Nexus4, SamSung, and HuaWei appear more colourful than those displayed on an iPhone. For example, the colours on a LG-Nexus4 phone appears systemically 10% more colourful than those depicted on an iPhone. In addition, for both HuaWei and SamSung phones, they appear again to be 17% and 22% more colourful, especially for colourful samples, the tendency presenting across all three phones. Since these findings are based on only one phone of each type, future study will focus on the investigation of large samples with more similar phones.

4. CONCLUSIONS

With 85% smartphone users perform their everyday tasks [Salesforce] using the device due to its ability and connectivity, smartphone continues to revolutionize how people perform their everyday activities. It is expected that this work will contribute to this revolutionary and complement users with some information when they perform online shopping buying colour incentive goods.

In summary, in terms of the measurement on each phone, encouragingly, the variations among the same kind of phones are insignificant with less than 3 ΔE CIELAB units. In addition, when comparing with subjects' hue estimations, all phones and the CRT monitor appear to have similar hue values, indicating that the hue values have been well reserved on those phones although some variations among phones are observe red. However, when it is viewed on a phone, a colour appears to show at variance with colourfulness by appearing much more colourful. Furthermore, the correlation coefficient (r) for CIELUV L* are 0.963, 0.959, 0.960, and 0.940 for iPhone, LG Nexus4, HuaWei and SamSung respectively, and are 0.890, 0.876, 0.761, and 0.764 respectively for CIELUV C* when comparing with the counterparts on the CRT monitor. Therefore, the iPhone tends to be the best with fewer scatterings. To predict a colour on a mobile phone using CIECAM02, the predictions rest on a number of environmental parameters settings, e.g., f = 0.9, c = 0.59, and nc = 0.90, which gives closer results with less scattering. Consequently, for an image with truthful colour to be displayed on a mobile phone, the forward and reverse model of CIECAM02 will have to be applied. Specifically, for iPhone5, nearly half of the colourfulness predicted by CIECAM02 need to be factored into. Further studies are in place to take more number of phones into consideration.

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