Incorporating JND into the Design of Mobile Device Display

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Abstract. The main purpose of this article is to incorporate the JND (Just Noticeable Difference) into the design of mobile device display, especially LCD display of mobile phone. JND is the difference threshold between stimuli that can be detectable by human sense. Thirty participants were employed for two experimentations in order to find out JND value of sensation for LCD. The critical design variables of LCD and the affective component of user satisfaction were investigated using AHP and regression analysis. Finally, the JND of design variables of LCD and its characteristics were investigated.

Keywords: Mobile device, Display, JND, LCD.

1 Introduction

As information technology has developed speedy and digital convergence has been accelerated, mobile device has used in many cases and its user has increased rapidly. The trend of mobile device development is smaller, lighter, and multi-functioned [1]. Especially a small size and low image quality of display penal are handicaps of usability and satisfaction. For example, since a mobile phone, one of the representative mobile device, has limited the physical user interface due to its small display penal and button in spite of many functions, many users have difficulties in using mobile phone [2]. Especially, the small display of mobile phone with high-resolution images could cause considerable users' dissatisfaction due to the unnecessary delay for calculating of unimportant scene feature below the threshold of human sense of sight [3]. In fact, all components of the display characteristics are not responsible for user satisfaction while user experience and the improvement of all components of display may not guarantee user satisfaction.

In case of the design of small display, the concept of JND (Just Noticeable Difference) might be useful in that it could suggest an acceptable range of design specifications of the display. It is expected that incorporation of JND into the design of mobile device display can reduce perceptual redundancy to make physical user interface of

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the display more usable. However, the previous studies on incorporating JND into the design of mobile device display are relatively few while many studies are available in the area of the image processing, virtual reality, speech recognition etc. [4, 5, 6]. In this study, we aim to investigate critical design variables of display for user satisfaction using the concept of JND and to suggest the design guideline of the variables of mobile device display.

2 Method

2.1 Experiment 1: Evaluation of User Satisfaction

We explored 22 affective components from the previous studies on usability and evaluation of affective satisfaction of mobile phone [7, 8]. We also analyzed hierarchical structure of the extracted affective components utilizing AHP. AHP is a mathematical decision making technique that allows consideration of both qualitative and quantitative aspects of decisions [9]. Table 1 shows seven affective components that were screened by expert panel.

Table 1. Seven affective components

No.	Affective component	Definition
1	Brightness	the quality or state of being bright
2	Clearness	the degree of distinguishable between colors
3	Color sense	the image of color of display
4	Reality	the degree of reality of display
5	Cubic effect	the degree of cubic effect of display
6	Craftsmanship	the degree of craftsmanship of display
7	Satisfaction	the degree of user satisfaction

We also investigated various design variables affecting LCD image quality such as DPI, brightness, contrast, color, angle of vision, and a delay of response from related works [10, 11]. We analyzed hierarchical structure of extracted components utilizing AHP again. After expert review, table 2 presents finally extracted four design variables and their definitions.

Table 2. Design variables affecting LCD image quality

No.	LCD component	Definition
1	DPI	Dot Per Inch
2	Brightness	the quality or state of being bright
3	Contrast	the degree of difference in tone between the light and dark partials
4	Color(RGB)	the particular visual sensation produced in this way, depending upon the wavelength

We simulated experimental environment using a 17-inch LCD monitor of computer (Hewlett-Packard 1702, pixel 800*600) instead of a LCD of mobile phone. The experimentation was implemented in a dark room in order to avoid compounding effects resulted from uncontrollable factors. Thirty participants, who had normal eyesight and were twenties, were recruited from the graduate student population. Fifteen different images were prepared for the experiment. The sample image size was 3cm*4cm as same as the mobile phone LCD size. The outer area of the sample image was painted in black as shown in Figure 1 and the sample images were presented in random order. The participants were asked to execute the experiment away from 30cm simulating usage of mobile phones. Table 3 shows the definition and variation of each variable, and Table 4 shows the specifications of the sample images.

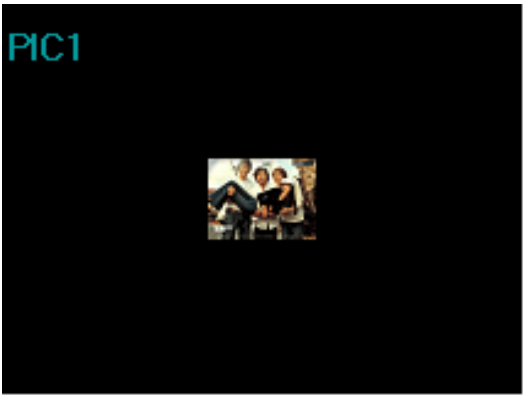

Fig. 1. The images were painted black outside the sample pictures

Table 3. The definitions and variations of each variable

Variables	The definitions and variations
DPI	DPI (dot per inch) is the number of pixel per inch and the index of resolution of display. From 36 to 200 DPI images were prepared for experiment.
Brightness	Brightness of images was measured by average of luminance.
Contrast	Contrast of images was measured by standard deviation of luminance.
Color (red, green, blue)	Color (red, green, blue) of images were prepared by variation of a quantity of red, green, blue.

2.2 Experiment 2: Measurement of JND

The concept of threshold is mentioned by the first stimulus strength to sensor. Threshold means the boundary of detectable sense. The minimum difference of two other stimuli is just noticeable difference (JND) [12]. Ernest Weber, a psychophysicist,

Table 4. The specifications of sample images

DPI	Brightness	Contrast	Red	Green	Blue
50	104.86	82.85	114.39	103.64	86.05
36	111.45	51.24	132.76	104.38	91.61
200	101.17	83.53	123.67	94.55	76.04
200	100.93	68.15	101.41	101.21	98.20
200	106.21	99.69	118.33	104.06	85.09
130	115.62	88.53	119.38	121.84	72.66
200	106.41	83.66	105.32	112.78	76.07
50	145.42	55.37	146.97	145.83	139.2
200	104.8	59.07	111.54	103.91	91.57
96	77.72	78.64	76.72	80.81	63.76
200	80.35	77.93	89.32	79.35	61.85
40	207.9	64.84	203.6	210.02	208.37
200	97.97	84.61	105.29	94.56	96.31
72	92.48	67.70	102.79	80.70	126.62
200	132.31	80.29	141.64	130.71	115.74

formulated $K=\Delta I/I$. K is Weber constant, ΔI is variation of the minimum difference of two other stimuli, and I is a reference of stimulus. Weber constant means that if a reference stimulus is larger, variance of stimulus is much larger. To the contrary, if a reference stimulus is smaller, variance of stimulus is much smaller.

The participants and experimental setup are prepared as same as experiment 1. We showed the images of 5 DPI and gradually higher by 20 DPI with an interval of one, and showed the images of 40 DPI and gradually higher by 150 with an interval of 10 for the sensitivity of DPI changes. We assumed the same Weber constant at other different DPI. We measured JND of DPI using mean value of three times measurement for each participant. Table 5 shows the scenario of experimental procedure.

We measured JND of 70.5 contrast (STD of luminance) and showed the images four times randomly to each participant as shown in Table 6. We measured JND of 92.54 brightness (average of luminance) and showed the images four times randomly to each participant as same as measurement of contrast. We prepared the controlled image of color (186 red, 171 green, 159 blue), and varied the color of images. The images were also presented randomly.

Table 5. The scenario of procedure for JND measurement of DPI

Image(DPI)	Ref.	off	6DPI	off	Ref.	off	7DPI	off	Ref.	off
Time(sec)	5	2	2	2	2	2	2	2	2	2
Image(DPI)	8DPI	off	Ref.	off	9DPI	off	Ref.	off	10DPI	off
Time(sec)	2	2	2	2	2	2	2	2	2	2

Table 6. The scenario of procedure for JND measurement of Contrast

Image(Contrast)	Ref.	off	74	off	Ref.	off	75	off	Ref.	off
Time(sec)	5	2	2	2	2	2	2	2	2	2
Image(Contrast)	76	off	Ref.	off	77	off	Ref.	off	78	off
Time(sec)	2	2	2	2	2	2	2	2	2	2
Image(Contrast)	Ref.	off	69	off	Ref.	off	68	off	Ref.	off
Time(sec)	5	2	2	2	2	2	2	2	2	2
Image(Contrast)	67	off	Ref.	off	66	off	Ref.	off	65	off
Time(sec)	2	2	2	2	2	2	2	2	2	2

3 Results

3.1 Experiment 1: Evaluation of User Satisfaction

The purpose of experiment 1 was to identify critical components to user satisfaction of LCD. We performed multiple regression analysis in order to investigate relationship between satisfaction of LCD and selected variables. Table 7 presents the result of multiple regression analysis. This model showed statistical significance ($p<0.0001$) with R-square = 0.84 and MSE = 23.58. Multi-collinearity is rather high due to color.

Table 7. The result of multiple regression analysis

Variable	Estimate Parameter	Standardized Estimated Parameter
Craftsmanship	5.53	0.44
Clearness	3.34	0.29
Reality	2.83	0.25
Cubic effect	3.41	0.31
Color sense	2.42	0.22
Brightness	-0.20	-0.40
Contrast	-0.21	-0.26
Color	0	0.12

We further analyzed partial test of each variable since some variables may have significant effect though result of multiple regression analysis indicated they were non-significant variables. Table 8 shows the partial model of DPI and contrast. The DPI and contrast model were statistically significant ($p<0.001$), and the interaction of other variables was not found at any significance level. The partial model of brightness was not statistically significant ($p=0.59$) and the interaction of other variables was significant at 0.1 significance level in brightness*contrast, brightness*red and brightness*blue. The partial model of color is statistically significant ($p<0.0001$) and the interaction of other variables was not significant at 0.1 significance level except for red*green. Table 9 shows that green, blue, green*blue, and red*green*blue were statistically significant factors.

Table 8. Partial model of DPI and contrast

DPI		Contrast	
Parameter	Estimated value	Parameter	Estimated value
Intercept	-12.45	Intercept	-67.12
DPI	1.41	lumin_std	3.05
DPI *DPI	-0.01	lumin_std*lumin_std	-0.02

Table 9. Partial model of color

Parameter	Estimated value
Intercept	1056.90
red	-3.24
green	-31.62
blue	14.62
red*green	0.00
red*blue	-0.09
green*blue	0.06
red*green*blue	0.00
red*red	0.06
green*green	0.14
blue*blue	-0.04

3.2 Experiment 2: Measurement of JND

The purpose of experiment 2 is to measure the JNDs of four variables identified by experiment 1. The measurement of JND is determined by 50% probability of change detection. The detection probability of each DPI, contrast, brightness and color (red, green, blue) were plotted and estimated. The estimated equation can calculate the point of 50% probability of detection. The calculated JND may inform of characteristics of each variable.

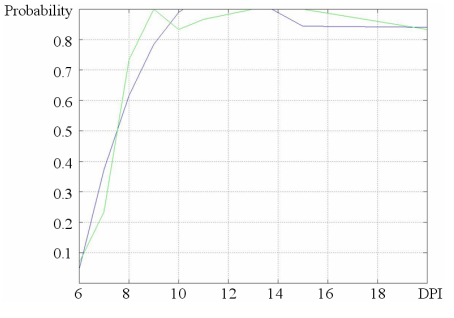

Fig. 2. JND of 5 DPI

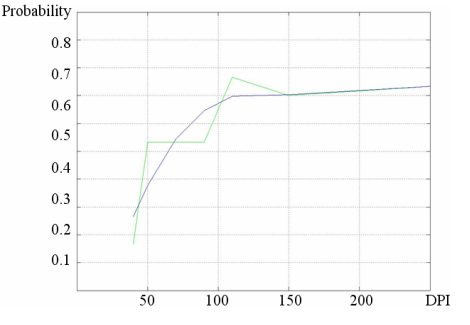

Fig. 3. JND of 40 DPI

Fig. 2 and Fig. 3 show the probability of DPI. The dotted line is the detection probability, and the solid line is the estimated probability. According to the result, the JND of 5 DPI is 6.94 DPI, and that of 40 DPI is 63.95 DPI. The Weber constant of 5 DPI is 0.39, and that of 40 DPI is 0.59. This result is not the same Weber constant. It is assumed that the relation between change of DPI and feelings of human is not multiple but rather quadric. If we know the DPI value that human cannot detect its change, we can calculate the acceptance range to measure JND of that value. Fig. 4 shows the probability of contrast. The JND of contrast is 64.20 in case of decrease, and 82.07 in case of increase. The Weber constant of decreasing contrast is 0.09, and that of increasing contrast is 0.16. If we adjusted less contrast in case of decrease than increase, it may be possible to reduce discordance of detection. Fig. 5 shows the probability of brightness. The JND of brightness is 80.26 in case of decrease and 106.08 in case of increase. The Weber constant of decreasing brightness is 0.13 and that of increasing brightness is 0.14.

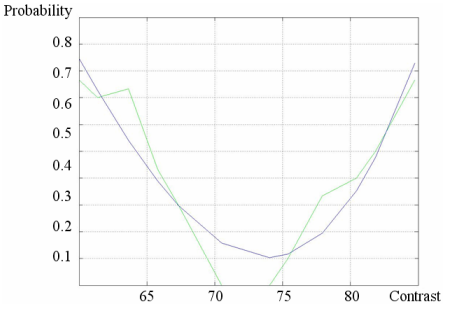

Fig. 4. JND of contrast

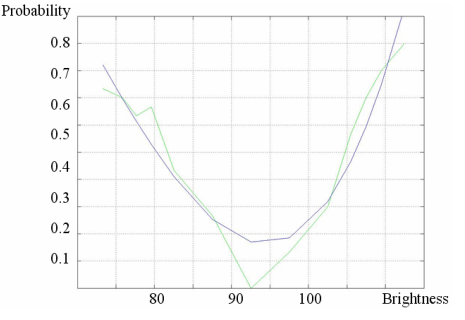

Fig. 5. JND of brightness

Fig. 6, 7, 8 shows the probability of color (red, green, blue) and Table 10 shows the JND of each color. Since color is composed of red, green and blue, the relative ratio of JND is significant for JND of color. Fig. 9 presents that JND of red is denser than green and blue. This means that human is more sensitive by change of red, and less sensitive by change of blue.

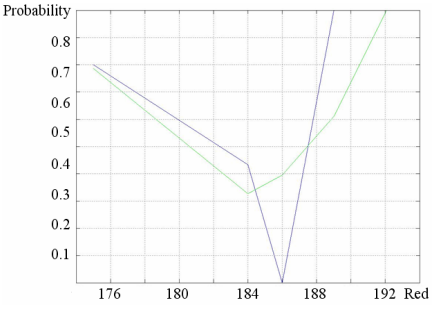

Fig. 6. JND of red

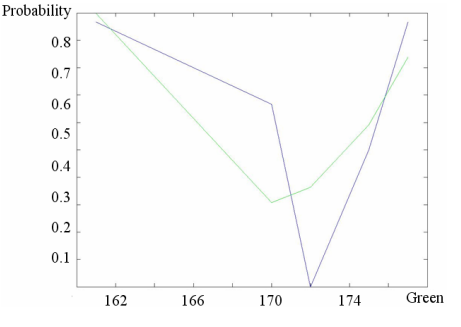

Fig. 7. JND of green

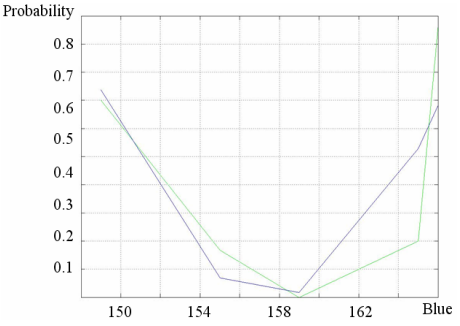

Fig. 8. JND of blue

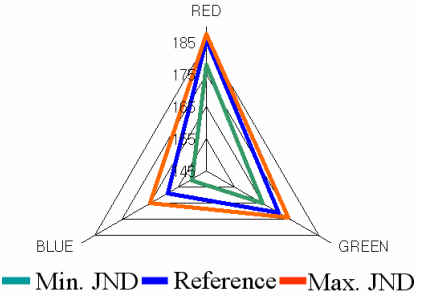

Fig. 9. Comparison of JND range of each color

Table 10. JND of color

Color	JND (decrease)	Reference	JND (increase)
Red	177.93	186.00	187.70
Green	165.01	171.00	174.04
Blue	150.53	159.00	164.80

4 Conclusion

The results of this study allow us to conclude that DPI, contrast, brightness and color (red, green and blue) are the critical design variables of the display of mobile phone for user satisfaction. The JNDs of the design variables were calculated and the characteristics of them were identified by the results of experiments. It is expected that the result of this study could be utilized to suggest design guidelines of mobile device design. There are many matters to be further investigated, such as experimental environment, types of images, individual difference, etc. In this study, we used a LCD monitor of computer instead of a LCD of mobile device so that potential discrepancy between related studies on JND might be found in result. Since the experiments in this study were implemented in laboratory environment, further study should be followed in various mobile environments considering inherent characteristics of mobile device.

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