Enhancement of Visibility by Adjusting Brightness based on App Image Categorization in Mobile Device

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Abstract

The visibility of images displayed on mobile devices can vary significantly according to the lighting conditions. Generally, the brightness of a mobile device is adjusted to enhance visibility according to the intensity of illumination. However, different brightness settings can be more suitable to different types of content even under the same illumination. Accordingly, this paper presents a method to adjust a device's brightness according to the features of the displayed app images. We started by performing two subjective tests under various lighting conditions for selecting the features concerning visibility for several apps screenshots and for selecting a satisfactory range of device brightness for each of those. Then, we analyzed the relationship between the app image features and the satisfactory brightness levels. Subsequently, the images are categorized by using two features: the average brightness and the distribution ratio of advancing colors related to satisfactory brightness. The optimal device brightness for each category is then selected by the maximum frequency of satisfactory device brightness. Experimental results show that the categorized app images with optimal device brightness have high satisfaction ratio under various light conditions.

Introduction

Display devices are generally used in indoors, so that many display manufacturers have tendency to focus on the areas of color fidelity, screen size, contrast ratio, and maximum luminance. However, viewing conditions such as intensity of illumination or color temperature of illumination have become important for mobile device[1],[2]. For example, we frequently encounter different intensities of illumination between office and outdoor environments, which can lead to decreased readability, gamut size, lightness and colorfulness of the display. In particular, images displayed under bright lighting condition are perceived as dark due to the light adaptation mechanisms of human visual system and various algorithms have been suggested to solve this problem.

Many approaches in literature suggest image enhancement for adjusting perceived brightness. For example, the logarithmic and power functions have been used to such extent [3]. However, these simple approaches have the disadvantage of washing out the color of the displayed image. Monobe proposed a method for preserving local contrast in various lighting conditions [4]. This method can effectively preserve the local contrast of an original image. However, the computational complexity is high and the enhanced image is affected by noise.

Another method is to control the back-lighting unit by using a light intensity sensor [5]. However, this method sets the brightness level only according to ambient condition, not content. Generally, different brightness is preferred according to content features even in the same lighting condition.

Accordingly, to enhance visibility under various lighting conditions, this paper presents adjusting device brightness according to the features of app images. First, the proposed method performed two prior subjective tests under various lighting conditions for selecting features of app images concerning visibility and for selecting satisfactory range of device brightness for each app image. Then, the relationship between selected features of app image and satisfaction range of device brightness is analyzed. Next, app image is categorized by using empirical threshold for each category based on two features of average brightness of app image and distribution ratio of advancing colors that are related to satisfactory range of device brightness. Then, optimal device brightness for each category is selected by having maximum frequency of satisfaction device brightness. Experimental results show that categorized app images with optimal device brightness have high satisfaction in various light conditions.

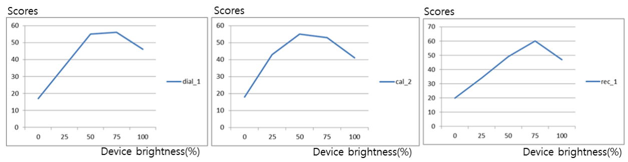
Selection of app image features and satisfactory brightness range

Two subjective tests were performed to determine which app image features should be used for selecting the display brightness level and the suitable brightness level for each category of app image.

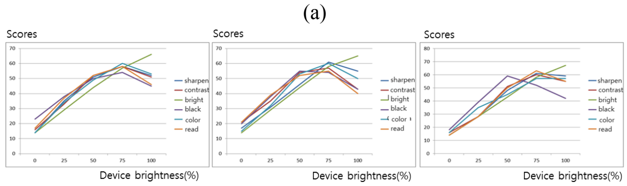
Selection of app image features concerning visibility

To select the app image features for visibility, a subjective test was performed on the sharpness, contrast, brightness, black level, color, and readability. The visibility was measured based on the user preference of a particular app image at different brightness levels. The test app images were all screenshots of applications, such as a dialer, calculator, voice recorder, etc.

The test was divided into two parts: one for deciding the representative screenshots and the other for deciding the representative features. Each observer evaluated the visibility of every app image on a scale from 1 to 5 when using 5 different levels of brightness: from 0% (device minimum) to 100% (device maximum) in 25% increments. Fig. 1(a) shows the scores for the dialer, calculator, and voice recorder screenshots. Fig. 1(b) shows the scores for six features of the same test images. Six of these features: the sharpness, contrast, brightness, black level, color, and readability all showed a similar relationship to the visibility when changing the device brightness from 0% to 100%.



(a)



(b)

Figure 1. *The relationship between visibility and 6 features of app image according to device brightness: (a) the scores of app images of dial, calculator, and voice recorder for five device brightness of 0, 25, 50, 75, and 100%, (b) the scores of six features in same app images according to five device brightness.*

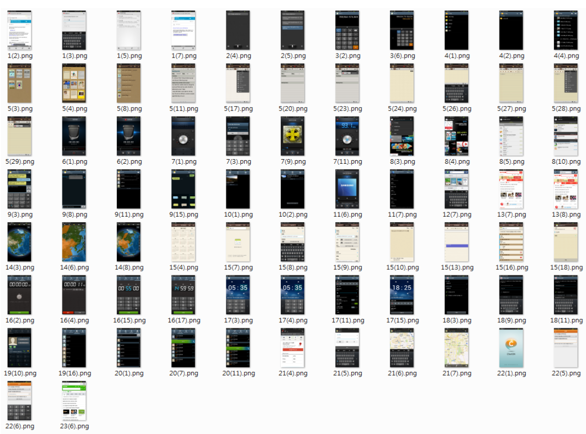


Figure 2. *79 Representative app images for pre-loaded application in Galaxy Note 3.*

Selection of satisfactory range of device brightness under various light conditions

To select a satisfactory range of brightness, a subjective satisfaction test was performed using screenshots of applications on a Samsung Galaxy Note 3. From a total of 260 screenshots of 23 pre-loaded programs, 79 representative images were selected. As shown in Fig. 2, the representative app images were composed of main application screens, as well as single-frame and multi-frame applications.

In the satisfaction test, the 79 app images were divided into two groups of 40 and 39 images to consider the concentration and eyestrain of the observers. Each image group was alternatively tested on the observers, as shown in Fig.3. Among the 30 observers, 10 were female and 20 were male, and the ages ranged between 20 and 35. The lighting conditions included 5, 50, and 500lux. The device brightness under 5lux ambient lighting ranged from 0cd to 40cd, under 50lux the brightness ranged from 50cd to 90cd, and under 500lux the brightness ranged from 100cd to 120cd. In all cases, the brightness was incremented in 10cd steps.

Figure 3. *Visibility test using two groups.*

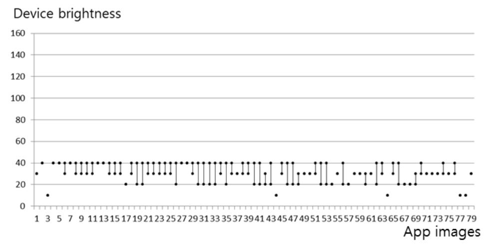


Figure 4. *The relationship between average luminance of app image and satisfactory ranges of device brightness under light condition of 5lux.*

Each observer declared satisfaction or dissatisfaction for each testing condition (app image, illuminant, brightness). If over 80% of the observers were satisfied with a particular brightness level, that level became a satisfactory brightness level. Next, the satisfactory ranges of brightness for each test image were analyzed.

Analysis of satisfactory range of device brightness and app image features

The satisfactory range of device brightness was used to analyze the relationship between the selected app image features and the visibility. First, the sharpness, contrast, and readability were analyzed using the contrast ratio. The black and brightness of the images were analyzed using the average brightness of each app image, while the color features were analyzed using the distribution ratio of advancing colors.

Analysis of relationship between average brightness and visibility

First, the image in RGB space was converted to CIELab color space by using sRGB model to calculate the average brightness of the app image[2]. The average of L calculated from CIELab color space was then used as the average brightness of the app image.

$$L_{avg} = \frac{1}{N}\sum_{i=1}^{N} L_i(x,y) \qquad (1)$$

Next, the app images were sorted in an ascending order based on the average brightness of each app image, along with the corresponding satisfactory ranges of device brightness, as shown in Fig. 4, thereby revealing the relationship between the average brightness and the satisfactory range of device brightness for the 79 representative app images. For all the test light conditions, the preference for the app images with a high average brightness was generally a low device brightness. Conversely, the preference for the app images with a low average brightness was generally a high device brightness.

Figure 5. *Exampled of app images; (a) app images with dark background and bright region, (b) multi-frame image, (c) bright gray background image.*

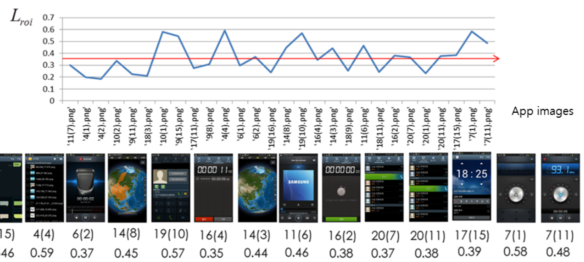


Figure 6. *App images with small average brightness and high average brightness in region of interest.*

Furthermore, Fig. 4 also shows several app images with a low average brightness where the preference was a low device brightness and several app images with a high average brightness where the preference was a high device brightness. In the former case, the app images were composed of a black background with a bright region, while in the latter case, the app images had a bright gray background, as shown in Fig. 5. Therefore, categorizing the image using only the average brightness was inadequate. Consequently, this paper used both the average brightness in the region of interest (ROI) and the distribution ratio of white pixels to categorize the app images.

Analysis of app image using average brightness in ROI

The ROI in an image is firstly calculated by using GBVS(graph-based visual saliency)[6]. Next, RGB values are converted into CIELab color space by using sRGB model, and then average L value of ROI in an app image, L_{roi}, is calculated for each app image with small average brightness.

$$L_{roi} = \frac{1}{N_{roi}} \sum_{i \in roi} L_i(x, y) \tag{2}$$

where N_{roi} represent the total number of pixels in ROI. The average brightness in the ROI for the app images with a low average brightness is shown in Fig. 6. As a result, the app images in Fig. 6 have a high average brightness in the ROI. Therefore, in this paper, the average brightness in the ROI for the app images with a low average brightness was used to categorize the app images.

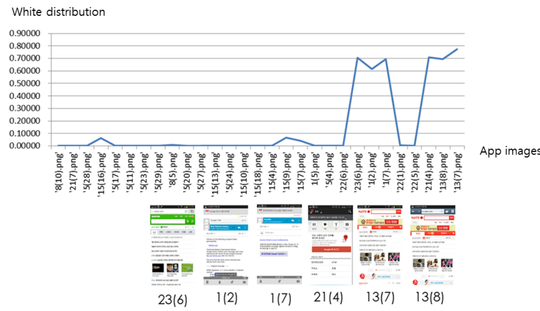


Figure 7. *App images with large average brightness and high distribution of white in an app image.*

Analysis of app image using distribution ratio of white pixel

White pixel is represented RGB value of 255, 255, 255 in an app image. Then, distribution ratio of white pixel is calculated by using the ratio of the number of white pixels to the number of total pixels in an app image.

$$W_{dis} = \frac{N_W}{N_t} \tag{3}$$

where N_W and N_t are the number of white pixel and the total number of pixels, respectively. The distribution ratios of white pixel for app images with large average brightness and app image having high white distribution ratio are shown in Fig. 7. Therefore, distribution ratio of white pixels is used to categorize the app image with bright gray background.

Analysis of app image using distribution ratio of achromatic pixels

App images are generally used achromatic background of white, black, and gray. Therefore, achromatic distribution is also used to categorize app image. Achromatic distribution is calculated by excluding the black pixels because black background is categorized by using average brightness of app image. To exclude black, the luminance value and chrominance value are respectively set to over 0.2 and to under 0.1, empirically. Achromatic region is determined as follows.

$$R_1 = \begin{cases} L \geq 0.2 \\ 0 \leq C_{ab} \leq 0.1 \end{cases} \tag{4}$$

Then, achromatic distribution ratio is calculated by using the ratio of the number of pixels within region R_1 in an image to the number of total pixels in an app image.

$$A_{dis} = \frac{N_{R_1}}{N_t} \tag{5}$$

where N_{R_1} and N_t are represent the number of pixels within region R_1 in an app image and the number of total pixels in an app image, respectively.

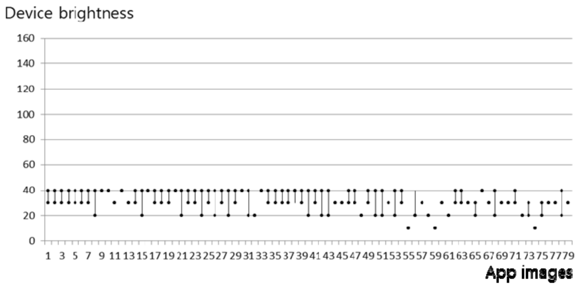


Figure 8. The relationship between average luminance of app image and satisfactory ranges of device brightness under light condition of 5lux.

Analysis of relationship between contrast ratio and visibility

RGB values are converted into CIELab values by using sRGB model. Then, L values of an app image and Michelson's contrast fomula are used to calculated contrast ratio M of an app image[7].

$$M = (L_{\max} - L_{\min}) / (L_{\max} + L_{\min}) \quad (6)$$

where $L_{\max}$ and $L_{\min}$ are maximum L value and minimum L value in an image, respectively. App images are ranged in ascending order based on contrast ratio, and analyzed their corresponding satisfactory range of device brightness. However, for all test light conditions of 5, 50, 500lux, app images have various satisfactory range of device brightness according to contrast ratio. It also represents no relationship between contrast ratio and satisfactory range of device brightness.

Analysis of the relationship between distribution ratio of advancing colors and visibility

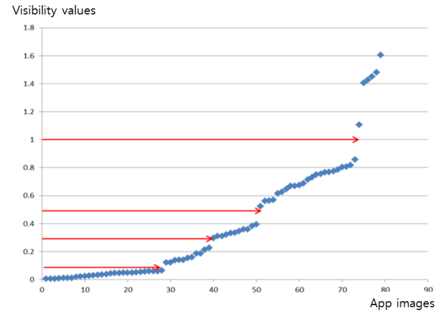
Perceived colors closer than the actual distance are determined as advancing colors in chromatics. Advancing colors are composed of colors with long-wavelength. Accordingly, red, yellow, and white are contained in advancing color[8],[9]. Therefore, the relationship between distribution ratio of advancing colors and visibility is analyzed. First, RGB values are converted into CIELCh color space[2]. Region of advancing color in CIELCh color space, R_2, based on chromatics was determined.

$$R_2 = \begin{cases} L \geq 0.5 \\ 0 \leq h_{ab} \leq 120 \ or \ 300 \leq h_{ab} \leq 360 \\ C_{ab} \geq 0.5 \ or \ 0 \leq C_{ab} \geq 0.1 \end{cases} \quad (7)$$

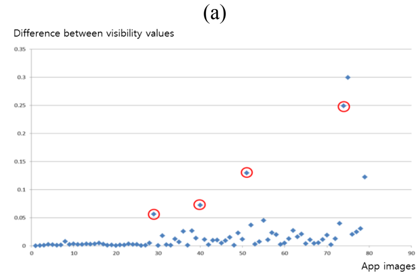
Then, distribution ratio of advancing color C_{adv} is calculated by using the ratio of the number of pixels of advancing color in an app image to the number of total pixels in an app image.

$$C_{adv} = \frac{N_{R_2}}{N_t} \quad (8)$$

where N_{R_2} and N_t are represent the number of pixels of advancing color in an app image and the number of total pixels in an app image, respectively. App images are sorted in ascending

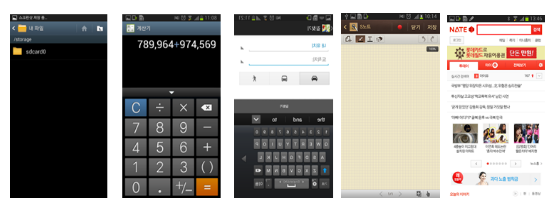


(a)



(b)

Figure 9. App image categorization using average luminance and advancing color: (a) visibility values of app images, (b) setting the threshold using difference of values.



(a) (b) (c) (d) (e)

Figure 10. Representative app images for each category: (a) category 1, (b) category 2, (c) category 3, (d) category 4, (e) category 5.

order based on distribution ratio of advancing color, and their corresponding satisfactory range of device brightness is shown in Fig. 8. For all test light condition, app images with large distribution ratio of advancing color are generally preferred low device brightness. On the contrary, app images with small distribution ratio of advancing colors are generally preferred high device brightness.

Categorization of app images using app image features

App images are can be categorize by using color and brightness of the mage because app images are artificially designed. Average brightness of app image and distribution ratio of advancing color is concerned with the satisfactory range of device brightness. Additionally, in case of app image with small average brightness, average brightness of ROI is used for app image categorization and likewise in case of app image with large average brightness, distribution ratio of white pixels is used for app image categorization.

Background of app image can be identified using parameters such as distribution of achromatic color, average brightness, and distribution ratio of advancing color. For example, background of app image with bright gray and white can be identified, if the app image has large distribution of achromatic color and large average brightness. Similarly, background of app image with dark gray can be recognized, if it has large distribution of achromatic color and small average brightness. Also, if app image contain small distribution of achromatic color and small average brightness then app image will have black background. Multi-frame app image has middle value of average brightness and large distribution of achromatic color. Therefore, it also can be categorized. Then, distribution ratio of advancing color is added to consider satisfactory device brightness for color feature.

Additionally, average brightness in ROI of app images with small average brightness and distribution ratio of white pixels of app image with bright gray background are used to categorize the app images. App image categorization is performed as follows.

$$visibility = \begin{cases} (C_{adv} + A_{dis}) \times (L_{avg} + L_{roi}), & (A_{dis} + C_{adv}) \times L_{avg} < 0.07 \\ (C_{adv} + (A_{dis} + W_{dis})) \times L_{avg}, & A_{dis} \times L_{avg} > 0.5 \\ (C_{adv} + A_{dis}) \times L_{avg}, & otherwise \end{cases} \quad (9)$$

Therefore, visibility value is calculated by using 79 representative app images. Then, these app images are ranged in ascending order using visibility value as shown in Fig. 9(a). Thresholds are detected by using large changes between visibilities of app images. Then, difference between visibilities of app images is calculated as shown in Fig. 9(b). Therefore, 79 representative app images can be grouped into 5 categories. The representative app images for each category are shown in Fig. 10. First category consists of images with black background, receding colors and the threshold is set to 0.07. The second category, contain black background images with dark gray keyboard and the threshold is set to 0.3. Third category consists of bright achromatic background images with dark gray keyboard and the threshold is set to 0.5. In the fourth category, bright gray and white background images with a threshold of 1.0. In the last category have bright background and advancing colors.

Experimental results

For the experimental evaluation of the proposed adjusting device brightness according to app images, an observer's satisfaction test was performed by using app images in Galaxy S4. To do that, optimal device brightness for each category is determined by having the maximum frequency of satisfactory device brightness from pre-performed experiment for selecting satisfactory range of device brightness. Optimal brightness for each category is presented in Table 1.

The satisfaction test for optimal device brightness was participated by 25 observers, 10 females and 15 males, aged between 20 and 35, under various light conditions of 5, 50, and 500lux. Each observer selects satisfaction or dissatisfaction for each category image with optimal device bright. The results of satisfaction test for each category under various light conditions of 5, 50, 500lux are presented in Table 1 by using average satisfaction rates. Therefore, categorized app images with optimal device brightness have high satisfaction rates with over 80%.

Table 1. The optimal device brightness for each category and the evaluation of the proposed method using average satisfaction rates.

Categories of app image	Optimal device brightness under various light conditions(cd/m^2)			Average satisfaction ratio(%)		
	5lux	50lux	500lux	5lux	50lux	500lux
1	40	80	120	88.8	88.8	97.5
2	40	70	110	96.2	96.2	93.7
3	40	70	110	88.8	99	98.1
4	30	60	100	90.9	99.3	99.3
5	20	60	90	88.8	98.6	99.3

Conclusion

We proposed a brightness adjustment method using app image categorization in order to enhance visibility in mobile devices. To determine which app image features were related with visibility and which brightness ranges were satisfactory for the user, we ran an observer preference test on 79 screenshots from 23 different pre-installed programs under different lighting conditions (5, 50 and 500 lux). Then the relationship between app image features and brightness ranges was analyzed. Test app images were categorized by average brightness and distribution ratio of advancing color that concern changing device brightness. Finally, the optimal device brightness for each category was selected according to the maximum frequency of satisfactory brightness. Experimental results show that the proposed method leads to high user satisfaction.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Education, Science and Technology (MEST) (No. NRF-2013R1A2A2A01016105).

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