Reduction Condition of Flicker during Switching of Two-colors for Protection of Image Displayed on a Liquid Crystal Display

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Human eyes can perceive two different colors as a single blended color when they are switched at a high speed. If this characteristic is used to display an image on a Liquid Crystal Display (LCD), the color of the image perceived will differ from the color that is captured on the LCD screen. Thus, this display method can be expected to deter illegal copying of images. However, the flicker occurs only when two colors with different levels of brightness are switched. We have already studied whether flicker was felt under the conditions of different switching speeds and using combination of two grayscale images. The experiment established that the flicker can be reduced at a switching speed of 144 Hz and combinations with gradation values of 0-127 and 191-255. However, the condition for reducing the flicker when using grayscales of gradation values 127-191 was not clear. In addition, conditions for reducing the flicker when using other colors have not been clarified. Therefore, to clarify the condition for reducing the flicker, we examined if flicker was felt with the combination of two grayscale images, gradation values of which were split in increments of eight from 127 to 191. Furthermore, we evaluated whether flicker was perceived or not under the conditions obtained from the grayscale experimental results when the same system colors were switched. As a result, we identified the conditions that make it possible to reduce the flicker that occurs when switching the same system color.

Keywords: Successive additive color mixing, Visual characteristic, Liquid crystal display

1 INTRODUCTION

When different colors are switched at a high speed, the human eye can only perceive a blended color. If this color mixing method is applied to display an image on a Liquid Crystal Display (LCD), the color perceived by the viewer will differ from the colors being switched. In other words, the color of the image obtained by capturing the LCD screen will be different from the color perceived by the human eye because the screen copy key of the personal computer (PC) or the digital camera can capture the momentary display. Thus, the captured image will be identical to the image used for switching display. If we use this method to display images on an LCD display in a space such as a laboratory or office, we can improve image protection and prevent illegal copying of images containing confidential information, as shown in Figure 1 [1].

The authors have previously measured the chromaticity of the colors displayed when two different colors are switched on an LCD [2]. As a result, it became clear that the chromaticity of the colors displayed by switching (the color perceived by the viewer) equals the average of the two colors used for switching. Furthermore, a method for estimating the chromaticity of the colors displayed through the switching was proposed. This estimation method helps create an image with swapped colors by modifying the color of the original image.
viewer. Hence, the estimation method used for this study should avoid the risk of the negative influence on the body.

Thus, it is necessary to reduce the flicker. The authors have investigated the relation between the flickering and the change in luminance of the sub-pixels that constitute one pixel of the LCD [3]. As a result, it has become clear that flickering depends on the change in luminance of the sub-pixels, regardless of the color used for display switching. In addition, the authors have evaluated whether flicker was felt or not under the various conditions of different switching speeds and various combination of two grayscale images [4]. These experiments have established that the flicker can be reduced by using a switching speed of 144 Hz and combinations with gradation values of 0-127 and 191-255. However, the condition for reducing the flicker when using grayscale of gradation values 127-191 was not clear. In addition, conditions for reducing the flicker when using colors other than grayscale have not been clarified.

The final goal of this study is to develop a new image display method for deterring the illegal copying of the image displayed on the LCD. The aim of this study is to propose a condition that can display mixed colors by switching two colors without flicker. First, we examined if flicker was perceived for a combination of two grayscale images, gradient values for which were split in increments of eight from 127 to 191. Next, based on the experimental results obtained in this study and the results that we have already discussed [4], we simulated the flicker reduction condition. Finally, we evaluated if the flicker was felt under the simulated conditions when the same system colors were switched.

2 VISUAL CHARACTERISTICS AND COLOR DISPLAY MECHANISM OF AN LCD

2.1 Visual characteristics

A color mixing method that works by switching several colors at a high speed is called successive additive color mixing [5]. The human eye perceives an average of the colors used for switching display during successive additive color mixing. The human eye perceives colors through a cone located at its bottom [5]. We perceive colors when the cones react, as shown in Figure 2. Red, green, and blue cones react according to the wavelength of the light, and the colors are distinguished by the reaction of these cells.

In general, if the light source is shut off and on consecutively at a frequency of about 30-40 Hz or more, our eyes perceive flashing light as continuous light [5]. Based on this visual characteristic, the screen of an LCD is updated to a speed of 60 Hz. As a result, viewers can see the images displayed on the LCD screen without feeling any discomfort. That is, in order to perceive a blend of two colors to the viewers, it is necessary to update the LCD screen at a speed twice or more than 60 Hz. However, no instance of different colors being switched and displayed on the LCD screen has been observed. The speed of color switching at which flicker does not occur has not yet been established.

In order to prevent illegal copying of images, it is better that the two colors used for switching are as different as possible. However, flicker occurs when the brightness of the two colors used for switching is significantly different. The brightness level of the two colors at which flicker occurs has not yet been established.

2.2 Color display mechanism of LCD

The structure of the LCD used for displaying colors is shown in Figure 3. The LCD consists of a set of small points called pixels. A pixel outputs one color. The LCD is able to display various images on the screen by controlling each pixel’s colors. In addition, one pixel is composed of three types of sub-pixels. The sub-pixels control red, green, and blue lights according to the colors that the pixel should output. Given that the pixels are so small, the human eye is unable to distinguish the light originating from a sub-pixel. Hence, we are unable to view the light reflected from the three sub-pixels and perceive only the blended light.

When a pixel alternately displays red and purple colors, as shown in Figure 4, the red sub-pixel constantly outputs a red light, the green sub-pixel does not output any light, and the blue sub-pixel blinks. Hence, the perceived quantity of the blue light is reduced by half.

According to the Weber-Fechner’s law, the sensitivity of the human eye to brightness responds logarithmically to the gradation value indicated by the dashed line in Figure 5 [5]. Therefore, the LCD output light changes exponentially in order to adjust the impact of brightness so that we can perceive a linear gradation value as depicted by the chain line in Figure 5. This correction is called gamma correction. Flicker may or may not occur even if the difference between the gradation values of the two colors used for switching are the same. For example, flicker does not occur when there is a minor difference in brightness when dark colors are switched. However, flicker will occur when the colors of a medium brightness are switched. Therefore, we need to check the presence or the absence of flicker across the overall gradation combination.

3 EVALUATION EXPERIMENT ON FLICKER USING GRAYSCALE IMAGE

3.1 Experimental method

To identify the conditions for reducing flicker, we examined...
some combinations of two grayscale images. Specifically, the subjects look at an image displayed on the LCD screen by switching between two grayscale images with different gradation values, as shown in Figure 6. The subjects denote the switching display image they perceive to be flickering as "×" and the switching display image that they did not perceive to be flickering as "●." For this study, we defined "×" as the condition when the subjects perceive flickering or one or more of the following:

- Blinking
- Blinking of outline
- Change of color

We also define "no flickering" as the condition when subjects perceive an ordinary image devoid of any disruptions.

Figure 7 shows the experimental environment. Tables 1 and 2 list the technical specifications of the PC and the LCD used. The distance between the display and the subject was set to 60 cm, and the subjects viewed the screen from the front. The viewing angle of the LCD used was sufficiently wide as shown in Table 2. Additionally, we instructed subjects not to move their heads while watching the LCD, and monitored subjects. Therefore, the color tone and the brightness of the color displayed on the LCD were correctly presented to the subjects. The LCD was placed under a D65 light source that is used for color inspection. The luminance around the subject was in the range of 350 lux to 400 lux near the eyes, in the range of 328 lux to 354 lux in the room, and in the range of 221 lux to 287 lux on the desk on the LCD.

Table 3 lists the RGB values of the colors used for switching, which includes nine single color images. Nine types of grayscale images with gradation values increasing in steps of 8 within a range 127-191 were used. Two colors with different gradation values were selected from among nine types of colors to avoid overlap, and switching display using the selected two colors was performed (total 36 patterns).

The switching speeds were set at 144 Hz. The timing of switching of the images is synchronized with the screen update timing of the LCD, so that no flickering was observed due to the difference in timing.

The subjects used are 19 dark brown iris humans, including 16 men and 3 females in their twenties. The average age of subjects is 22.3 years old, and the standard deviation is 1.65. In addition, to evaluate the impact of the experiments on the bodies of the subjects, we distributed questionnaires regarding their physical conditions before and after the experiment (SSQ: Simulation Sickness Questionnaire) [6]. The SSQ contained 16 questions on headache, vertigo, nausea, eyestrain, and other symptoms. The data used in this study was acquired in accordance with the ethical regulations for studies conducted on humans framed by the Akita University.

### 3.2 Experimental result

As a result of asking SSQ before and after the experiment, 15 subjects had a score 0 (score 0 means that there is not an applicable item of the SSQ to the physical condition). Three subjects answered "I feel tired to the eyes" before and after the experiment (the score 1). The last one subject answered "I feel tired to the eyes" and "I look blurry" only after the experiment (the score 2). That is, it was clear that only one subject changed the physical condition in which
is not a dangerous change such as a headache. This result shows that the switching display method proposed has less influence on the physical condition.

Figure 8 shows the relationship between the percentages of the answers that "did not perceive flickering" and the difference in the gradation values of the two colors used for switching between gradation values 127-191. The horizontal axis indicates the gradation value of one color used for switching and the vertical axis indicates the difference of gradation values between the other color and the horizontal axis. Marks in the figures indicate the percentage of the answers that "did not perceive flickering." From Figure 8, it can be seen that the proportion of respondents who answered, "did not perceive flickering" in all combinations with the gradation value difference of 56 or less is 80% or more. The reason why the range of the gradation value difference without the flicker is narrow may be the visual system of the human eye that can finely discriminate the middle range of colors. The significant change in the brightness of the outputted light from the LCD at the middle gradation values may be another reason for the narrow range.

3.3 Assumption of reduction condition

Figure 9 shows the upper and lower limit of gradation value difference of "did not perceive flickering" in gradation value 127-191 convert from Figure 8. Figure 10 shows the upper and lower limit of gradation value difference of "did not perceive flickering" convert from experimental results at grayscale of gradation values 0-255 [4]. The horizontal axis indicates the gradation value of one color used for switching and the vertical axis indicates the difference of gradation values between the other color and the horizontal axis. The number next to the red arrow is the gradation value difference between upper and lower limits for the respondents who answered, "did not perceive flickering."

It is possible to reduce flicker in switching display by merging Figures 9 and 10 to combine the grayscale values for three conditions as shown below:
  · When the gradation value of one use color is 0-127, the difference from the gradation value of the other use color is set to 127 or less.
  · When the gradation value of one of the used colors is 127-191, the difference from the gradation value of the other used color is set to 56 or less.
  · When the gradation value of one of the used colors is 191-255, the gradation value of the other used color is also set to the gradation value within the same range.

4 EVALUATION EXPERIMENT ON FLICKER USING COLORS OF THE SAME SYSTEM

As described in Chapter 2, the pixels of LCD consist of three sub-pixels. From this, we can observe that switching display using a grayscale image is switched and displayed with the same system color for every three sub-pixels. So, if the three types conditions assumed in Section 3.3 are capable of reducing flicker in the sub-pixel switching display, the assumed conditions can be applied to all colors that can be displayed on the LCD.

4.1 Experimental method

We evaluated in the same evaluation method and experimental environment as in Section 3.1 about red, green and blue, which are elements of the sub-pixel. Specifically, as presented in Table 4, create two-color-combinations that the gradation value difference in the assumed conditions to maximum for each color. The switching speed only used 144 Hz.

4.2 Experimental result

Figure 11 shows the results of the experiments, indicating that the rate of answered "did not perceive flickering" for each color combinations in experiment. The red line shows that the proportion of respondents who answered, "did not feel flicker" is 90%. It can be seen that almost all combinations of the proportions of respondents who answered, "did not feel flicker"
reaches the red line. This result suggested that conditions of two colors combination is able to reduce flicker. However, the rate of answered "did not perceive flickering" in the green combination of 0 and 127 was lower than red line. Therefore, we can observe that we need to decrease the maximum of the gradation value difference of two colors combining in the range of 0-127. The maximum gradation value difference is 95 in the range of 0-127 can be further reduce flicker.

4.3 Definition of conditions for reducing flicker

Based on the experimental results described in Section 4.2, the flicker reduction condition is defined as follows:

(a) When the gradation value of one of the used color is 0-127, the difference from the gradation value of the other use color is set to 95 or less.

(b) When the gradation value of one of the used colors is 127-191, the difference from the gradation value of the other used color is set to 56 or less.

(c) When the gradation value of one of the used colors is 191-255, the gradation value of the other used color is also set to the gradation value within the same range.

5 CONCLUSION

In this study, to identify the reducible conditions that result in flickering when two different colors switch on the LCD, we examined if a flicker was perceived under conditions of combinations of two colors. The following results were obtained:

(1) We established that two colors combination conditions, which can reduce flicker within the range of gradation values from 127-191.

(2) When the switching speed was 144 Hz, it was shown that flickering can be reduced by performing switching display under the following conditions:

(a) When the gradation value of one use color is 0-127, the difference from the gradation value of the other use color is set to 95 or less.

(b) When the gradation value of one of the used colors is 127-191, the difference from the gradation value of the other used color is set to 56 or less.

(c) When the gradation value of one of the used colors is 191-255, the gradation value of the other used color is also set to the gradation value within the same range.

In future work, we develop a method of create two colors used for switching display from one color following these results.

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