Information Hiding in 60 Hz Video by Use of Temporal Color Fusion of Human Visual System

Shunsuke Mori[1] and Tomokazu Shiga[1]

s-mori@townsend.ee.uec.ac.jp
[1]Department of Engineering Science, The University of Electro-Communications, Japan
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ABSTRACT

A color pair which are symmetry about an original color in the CIELAB color space are displayed alternately at 60 Hz, human perceives the original color, while camera can obtain each color. When CIELAB color difference between the original and modulated colors is less than 10, flicker and color distortion are imperceptible.

1. Introduction

Various image hiding techniques using high frame rate video higher than 60 Hz has been proposed for the information transmission or protecting contents [1, 2]. We have also developed the same kind of technique using 120 Hz LCD [3]. Figure 1 shows a concept of our technique. A +ΔL image in which the luminance of a part of the image is increased and a −ΔL image in which the luminance is decreased by that amount are alternatively displayed every 1/120 second. Observer perceives the averaged luminance of these images by the Talbot-Plateau law which is one of the temporal properties of human visual system, and thus the original image is recognized. When the displayed image is captured by the camera with the appropriate shutter speed, hidden image can be obtained. We have confirmed that the QR code was successfully embedded and scanned with the technique. Unfortunately, 120 Hz display and video are not yet widely available. Adopting these techniques to the common 60 Hz display and video will cause unacceptable flicker. Another technique utilizing temporal fusion of different colors also proposed elsewhere [4]. In this study, the embedding conditions of the color modulation-based technique under which hidden image can be embedded without flicker and color distortion even at 60 frames per second (fps) is investigated.

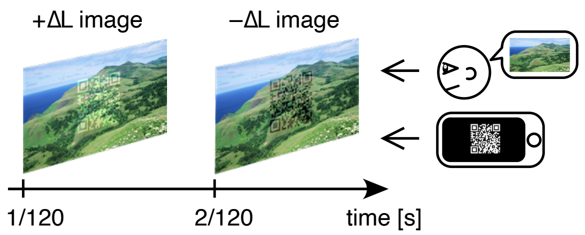

Fig. 1 Concept of image hiding technique with 120 frame per second video. +ΔL and −ΔL images are displayed alternatively. In this example, a QR code is embedded.

2. Methods

In the human visual system, human sensation to periodic visual stimulus becomes continuous at a certain frequency, and the effective stimulation will be the average during a cycle according to the Talbot-Plateau law. The frequency is the critical flicker-fusion frequency (CFF). At the luminance range of general TV display devices, CFF is 50-60 Hz. Therefore, a frame rates of 100Hz/120Hz or higher is often employed for the luminance modulation-based hidden image embedding techniques. Since CFF decreases with the contrast of luminance variation, flicker can be prevented by reducing the luminance modulation sufficiently even at 60 fps. However, in this case, camera also cannot extract the information.

CFF for chromatic contrast is lower than that for luminance contrast. Therefore, we employ color modulation for the proposed technique. Figure 2 explains concept of color modulation in our technique. The basic idea is almost the same as the method of Yamamoto et al. [4]. *RGB* value of an embedding pixel is firstly converted to *L*a*b** value in the CIELAB color space. Then a color pair, which are symmetry with respect to the original color position in the CIELAB color space, are calculated while keeping the lightness. The color pair are displayed alternatively at a certain frame rate. If the frame rate and color difference between the original and the modified pixels are set appropriately, the original color, which is average of two modified colors, is perceived without flicker.

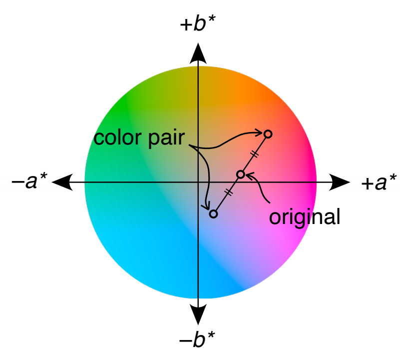

Fig. 2 Concept of color modulation.

The hidden image can be captured by the common camera, including smart phones. Note that the exposure time of the camera should not be set to an even multiple of the frame time of the display. When the images are taken successively at an odd multiple of the frame interval of the display device, the two modified images are captured. Finally, a binary image information is obtained by thresholding of the difference between these images. In addition, the technique can be used for the contents protection. When a human-imperceptible message such as “No Photo”, “Copy”, etc., is embedded, they will appear only in the captured photo or movie.

3. Experiments

The frame rate and the amount of color modulation should be set appropriately in order to prevent flicker and color distortion. In the present study, the appropriate amount of color modulation for various hues and lightness was investigated by the subjective evaluation experiment while keeping the frame rate at 60 Hz.

Figure 3 shows an example of the +ΔC and −ΔC image pair for the evaluation, consisting of central and peripheral areas. The lightness of the central area is identical to that of peripheral area, but the chromaticity coordinates is modulated by color difference *ΔC* from the values of the peripheral area. The central area’s chromaticity points of these images are symmetric with respect to the peripheral area’s chromaticity point.

In every evaluation trial, the +ΔC and −ΔC image were alternatively shown to the subjects at 60 fps. The subjects evaluated flicker of central area and color difference between the central and peripheral areas with a five-grade impairment scale listed in Table 1.

In the experiments, a 13.3-inch diagonal liquid crystal display having sRGB color gamut, D65 white point, and maximum luminance of 330 cd/m^2 was used. The viewing distance was three times the screen height. In this condition, the field size of central area of the test image

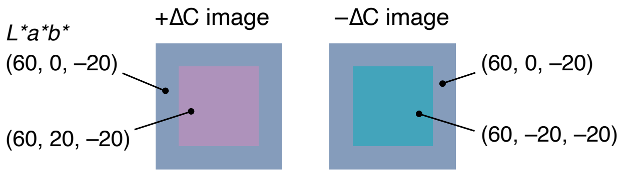

Fig. 3 Example of test image. *ΔC*=20.

Table 1. Five-grade impairment scale.

Rating	Impairment
5	Imperceptible
4	Perceptible, but no annoying
3	Slightly annoying
2	Annoying
1	Very annoying

was 6˚. Measurements were carried out in a living room condition with daylight color illumination. Illuminance of the room was 184 lx. Note that the luminance and color values of the test image were measured in a dark room. The subjects consisted of 5 males in their twenties with a normal color vision.

4. Results and Discussions

4.1. Luminance Modulation

Before showing the results of the color modulation, we first show the results of the luminance modulation. In this experiment, both the central and peripheral areas were achromatic ($a^*=b^*=0$) and lightness difference *ΔL* of the central area was varied. Mean of opinion score (MOS) of flicker as a function of *ΔL* is shown in Fig. 4. Even at 60 fps, flicker becomes imperceptible when *ΔL* is reduced. There is no significant difference in the results depending on the lightness. Here the evaluation values of 4.5 and 3.5 are defined as imperceptible limit and acceptable limit of perception, respectively. It can be found from the figure that these limits are attained when Δ*L* is 1.0 and 1.5, respectively. Weber contrast at Δ*L*=1.0 was less than 0.05 when $L^* \geq 57$ and gray level difference was only 3. It will be difficult to detect the difference by the common camera. Thus 60 Hz luminance modulation cannot be

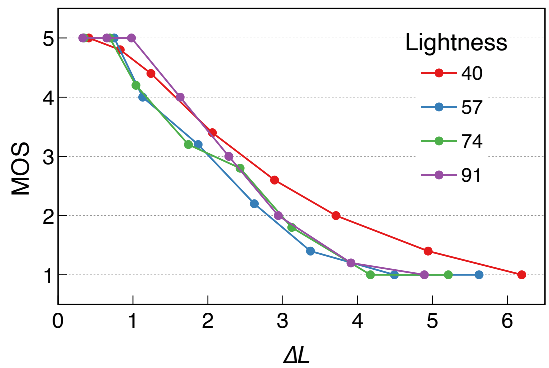

Fig. 4 Mean opinion score (MOS) of flicker visibility *vs. ΔL*. Luminance for *L*=40, 57, 74, and 91 were 30, 75, 147, and 236 cd/m^2, respectively.

used for image hiding technique.

4.2. Hue and Modulation Direction

Experiments for the color modulation were conducted using 9 colors of various hues at L^*=60 in the sRGB color gamut as shown in Fig. 5. The direction of color modulation was set to 0, 90, 45, and –45 degrees to the positive direction of a^*-axis. The averaged flicker evaluation values when *ΔC* were 15 and 20 are shown in Figs. 6. Note that all subjects gave a rating of almost 5 for the images with *ΔC* =10.

Evaluation values for the colors 7, 8, and 9 are lower than the others, especially when direction is 90˚. On the

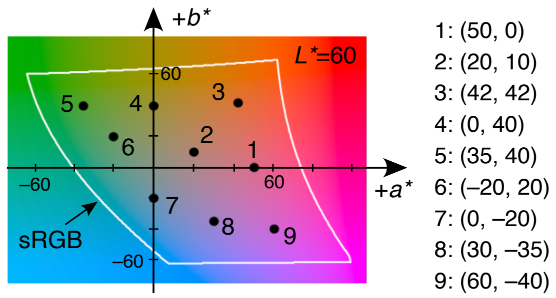

Fig. 5 Chromaticity point of the test images in the CIELAB color space. The numbers on the right side are *a and *b** coordinates of each point.**

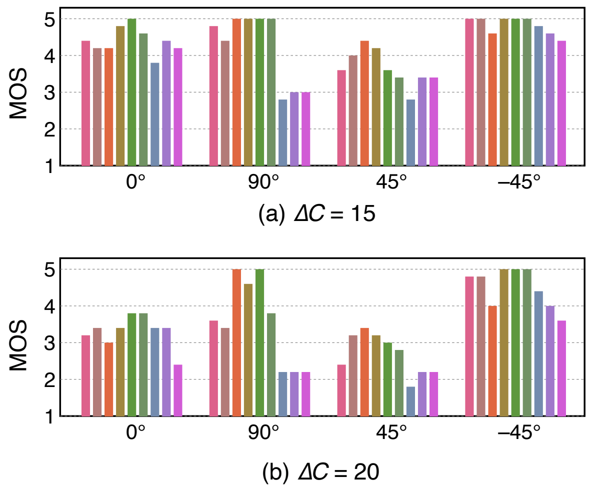

Fig. 6 Evaluation results of flicker visibility for various colors. The color of the bars corresponds to the colors of test image.

whole, however, the values do not depend so much on the hue. As for the modulation direction, the values are lower with 0˚ and 45˚, and higher with −45˚. Measured $L^*a^*b^*$ values were different from the set values due to $L^*a^*b^*$-RGB conversion errors and input-output errors of the display device. The difference in the measured lightness between the +ΔC and −ΔC images ranged from 0 to 1.5. Flicker visibility did not depend on the lightness difference. In contrast, there was non-negligible difference in the gray level of each subpixel. The magnitude of the difference depends on the modulation direction as shown in Table 2. Large change in R and G subpixels causes higher flicker visibility. On the other hand, large change in B subpixel do not have much influence since human visual sensitivity to blue light is lower. With −45˚, difference was not large for all subpixels, the higher evaluation value was obtained. In addition, evaluation values of color difference for −45˚ were higher than the others. In this study, ΔC was calculated using the delta E76 equation, thus it is not perceptually uniform in all hues and saturations. We have calculated the delta E00 for each color and compared it to the results, but no clear dependence has been found.

Table 2. Magnitude of gray level difference between the +ΔC and −ΔC images.

direction	R	G	B
0˚	large	medium	negligible
90˚	medium	negligible	large
45˚	large	small	medium
−45˚	medium	small	medium

It is concluded that the color modulation direction of −45˚ is appropriate for suppressing the flicker and color distortion.

4.3. Amount of Color Modulation

Figures 7 show the evaluation results as a function of *ΔC* for various L^* when chromaticity coordinates of the peripheral area was (a^*, b^*) = (30, 0) and the direction of color modulation was 90˚. The difference in the measured average lightness between the +ΔC and −ΔC images was less than 0.4. On the other hand, difference in B subpixel value increased significantly as *ΔC* increased. R subpixel value also changed, but the difference was 1/3 of the B subpixel.

As *ΔC* increased, the measured color value of the

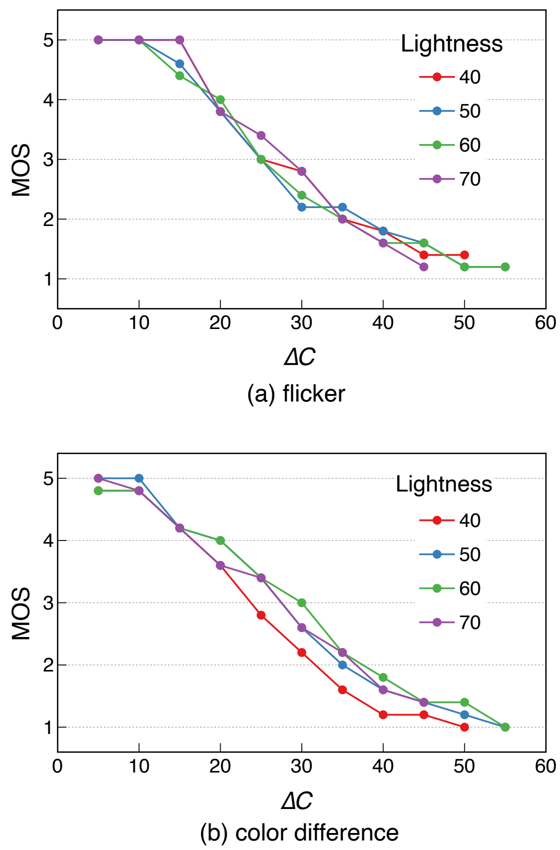

Fig. 7 Evaluation values vs. *ΔC*.

(a) 1/125 s (b) 1/125 s (c) 1/30 s

Fig. 8 Photos of test image (movie) for various shutter speed. The ISO sensitivity at shutter speed 1/125 s was 4 times higher. $L^*a^*b^*$= (40, 30, 0) and ΔC=10. (a), (b), and (c) correspond to +ΔC image, –ΔC image, and human perceived image, respectively.

central area shifted from that of the peripheral area. When L^*=60 or 70 and ΔC=15, the color difference was more than 1.2, which is categorized as "people can tell the difference, if the colors are put side by side". The measurement of gray-to-gray time response using a photosensor revealed that the slow rise and fall responses cause a lack or excess of light emission within a field. If the amount of lack is not equal to that of excess, the color shift will occur. The mismatch becomes large for larger gray-level transition.

It is found from the results that no flicker is perceivable with ΔC=10 and flicker is perceptible but not annoying with ΔC=20. When ΔC=10, the gray-level difference of B and R subpixels were more than 30 and 10, respectively. These differences are enough for detection by the common camera. For reference, captured photos are shown in Fig. 8.

5. Conclusions

Visibility of flicker and color distortion were measured for the color modulation-based image hiding technique. A color pair which were symmetry about an original color in the CIELAB color space were displayed alternately. Even at 60 fps, flicker and color distortion were imperceptible when the CIELAB color difference between the modulated and original value was 10. Color modulation direction of –45˚ was better than 0˚, 45˚, and 90˚ for suppressing the flicker and color distortion. The color difference of 10 generated a sufficient gray level difference for detection by the common camera. Since general image has more complex luminance distribution than the test image, flicker and color distortion are less noticeable. Therefore, larger modulation color difference could be applied, resulting in easier hiding image acquisition.

References

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