Hidden image display which required the special eyeglass for the viewer to observe the hidden image

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Abstract — Stenography is to conceal the hidden information within another information such that the hidden information can be extracted by the special technique. A steganographic display that required the special eyeglass for the viewer to observe the hidden image was newly proposed. In this hidden-image display, the viewers wearing the special eyeglass can observe the hidden image, while the viewer with the naked eye can not discern the hidden image. Working principle and the calculation scheme for the generation of input images was investigated. The estimation of the normalized luminance for the gray levels of each pixel on the display was required for the calculation. The concept was experimentally verified using the commercial 3D display based on the patterned retarder and the polarizing eyeglass.

Keywords *— steganography, 3D display, naked eye, eyeglass.*

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1 Introduction

There had been researches for the various 3D technologies.[1–9] Among these, 3D technologies using the special eyeglass became commercially successful for 3D TV and 3D movie. 3D display with the special eyeglass can provide the two separate images to the viewers by the special eyeglass. In 3D display with the special eyeglass, two types of 3D technologies were mostly used. One type used the display with the patterned retarder and the polarizing eyeglass.[5,6] The other type used the fast switching display and the shutter glass. [5,8,9] 3D TV was reported to occupy more than 20% of the TV market in the year of 2012.[10,11]

As 3D display with the special eyeglass became easily available, this technology was adapted for the new application called dual play (or dual view) TV where two viewers wearing the different types of eyeglass observe the two different images. [12] In case of 3D display or dual play display, the viewer without the special eyeglass is difficult to use the display comfortably as the viewer only see the overlap of the two different images.

Stenography is to conceal the information within another information such that the existence of the hidden data is unknown and the hidden data can be extracted by the special technique.[13] A display similar to stenography is newly considered that the viewers wearing the special eyeglass can observe the hidden image, while the viewer with naked eye can not detect the hidden image. This proposed display can also be used such that the viewers wearing the special eyeglass can observe the information, which does not hinder the viewing experience of other viewers without the special eyeglass.

In this paper, the working principle of the proposed display was described. Then, the proposed concept was experimentally verified, utilizing the technologies of 3D display with the special eyeglass.

2 Principle

2.1 Concept of the proposed display

Figure 1 illustrates the examples of the reported display applications that provide the separate images to each eye or two viewers by the special eyeglass. In case of 3D display application of Fig. 1(a), the transmitting characteristics of the left and right side of the eyeglass are different. [5–9] Hence, the two eyes of the viewer can see the different image through the special eyeglass. In case of dual play application of Fig. 1(b), the transmitting characteristics of the left and right side of each types of the special eyeglass are the same.[12] Two types of the special eyeglass are available. The viewers wearing the different types of the special eyeglass can see the different image through the special eyeglass. In these display applications, the viewer without the special eyeglass sees the overlap of the two different images for view 1 and view 2. Hence, these two examples may be considered to focus on the viewer wearing the special eyeglass.

Figure 2 illustrates the concept of the proposed display that the viewers wearing the special eyeglass can observe the hidden image or information while the viewer without the special eyeglass can not detect the hidden image. In Fig. 2(a), the original image, *Image_O* represents the image intended to be seen by the viewer without the special eyeglass. The images for view 1 represent the image intended for the viewer wearing the special eyeglass. And text information is inserted into image for view 1 compared with the original image *Image_O*. Images for view 1 and view 2 are generated such that the

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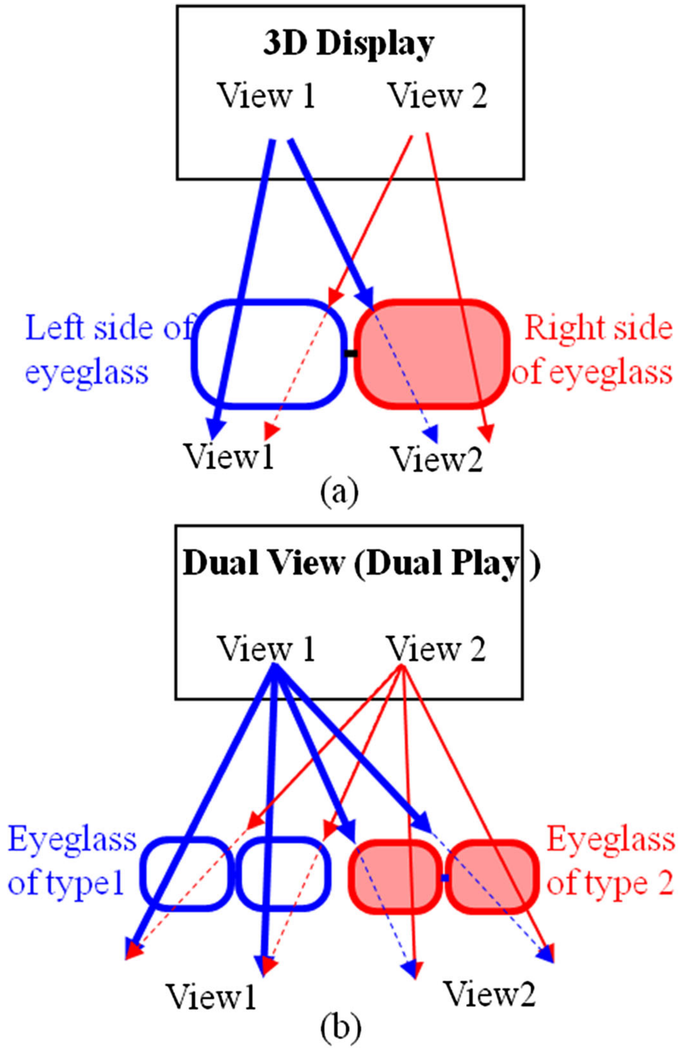

FIGURE 1 — Examples of display applications that provide the separate images to each eye or two viewers by the special eyeglass (a) 3D displays with the special eyeglass. Images for view 1 and view 2 correspond to the left and right images of the stereoscopic image. (b) Dual play or dual view. Images for view 1 and view 2 are two completely different images.

overlap of these two images composes the original image. Images for view 1 and view 2 correspond to the inputs of two views in 3D display. Figure 2(b) illustrated the proposal for the example of 3D display of the patterned retarder where the pixels of the horizontal even and odd lines of the display emit two orthogonally polarized lights. The images for view 1 and view 2 assign to the pixels of the odd and even lines. Hence, the images for view 1 and view 2 are vertically misaligned by the amount of one-line width. Polarization direction of lights from the pixels assigned to images for view 1 and view 2 are orthogonal. In this proposed display, the transmitting characteristics of the left and right side of the eyeglass are the same. If the special eyeglass blocks the polarized light coming from the even lines assigned to the image for view 2, the viewer wearing the special eyeglass can only see the image for view 1. Eyeglass used in the proposed display is different from that of 3D display and compatible with that used at dual play or dual view TV. The naked eye of the viewer cannot

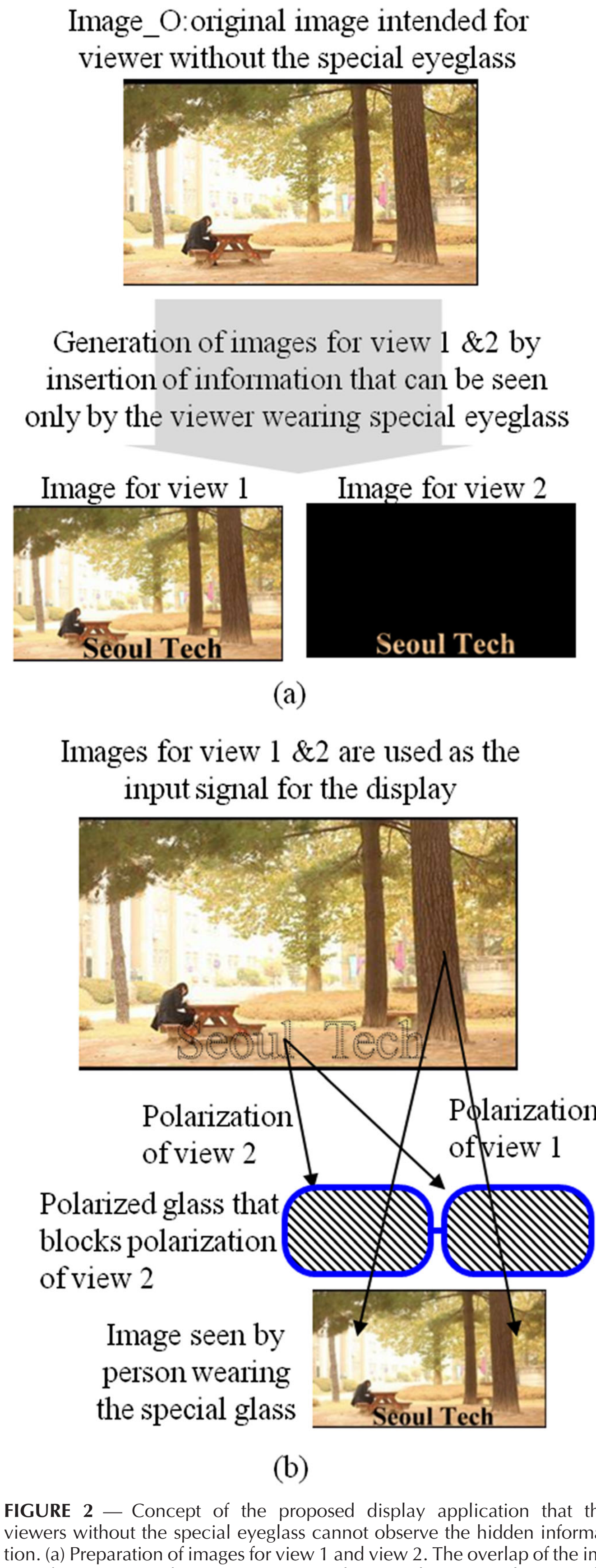

FIGURE 2 — Concept of the proposed display application that the viewers without the special eyeglass cannot observe the hidden information. (a) Preparation of images for view 1 and view 2. The overlap of the images for view 1 and view 2 composes the complete original image. (b) Example using the 3D display with the patterned retarder and polarized eyeglass.

discern the difference of the polarization directions, and the positional difference of one-line width is expected to be not noticeable when the viewing distance is large enough. So the viewer without the special eyeglass only sees the overlap of the images for view 1 and view 2.

The concept of Fig. 2 is also applicable for the fast switching display and the shutter glass. Figure 3 illustrates the examples of the hardware configuration of the proposed display adapting the technologies of 3D display with the special eyeglass. In case of the display with the patterned retarder of Fig. 3(a), the left and right side of the eyeglass only passes one polarization directions. So the viewer wearing this polarized eyeglass can see only the image on either even or odd horizontal lines of the display. In case of the fast switching display of Fig. 3(b), the transmittance of the shutter glass sequentially change such that only image of the even or odd frame can be seen through the shutter glass by the viewer. Viewers without the shutter glass can see the even frame and odd frame. When the temporal change of the even frame and odd frame is fast enough, the viewer without the shutter glass only sees the overlap of the images for view 1 and view 2.

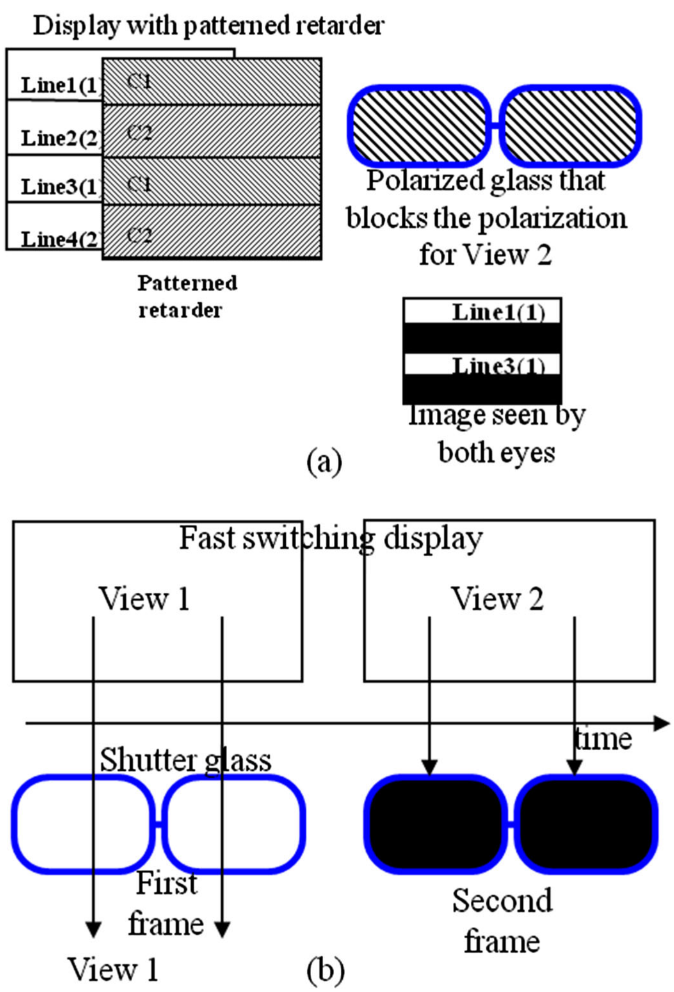

FIGURE 3 — Hardware configuration of the proposed display adapted to the 3D technologies using (a) the patterned retarder and (b) the shutter glass.

2.2 Calculation scheme for the image generation

Image that the viewer without the special glass can see is represented as *Image_O*. Image that the viewer without the special glass cannot discern is represented as *Image_I*. Image data are handled in the color space of RGB where each gray level of RGB is represented as the integer between 0 and 255. Gray levels at each pixel of *Image_O* and *Image_I* are represented as (R_0, G_0, B_0) and (R_i, G_i, B_i). (R_1, G_1, B_1) and (R_2, G_2, B_2) represent the gray levels at each pixel of the images for view 1 and view 2. The gray levels at the corresponding pixels of image for view 1 and view 2 can be determined by the calculation scheme as illustrated in Fig. 4.

As the relation between the luminance and the gray level of the display depends on the display characteristics, this relation needs to be characterized accurately. And from this relation, gray level needs to be converted to the normalized luminance. As an example, the relation between the gray level D_x and the

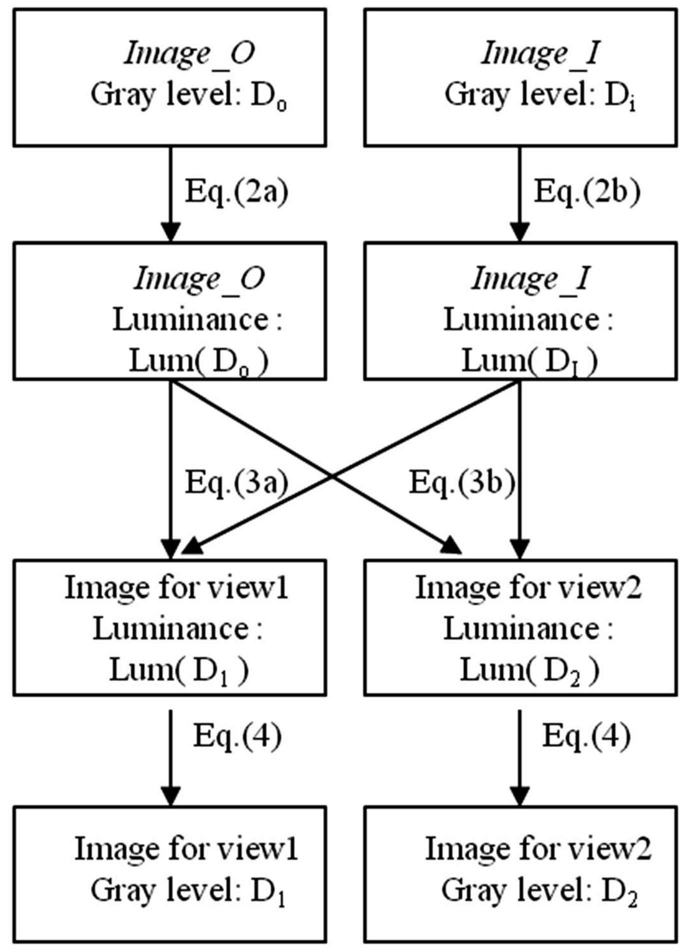

FIGURE 4 — Calculation scheme for the generation of images for view 1 and view 2 from *Image_O* and *Image_I*. D_O, D_I, D_1, and D_2 represent the one of RGB gray levels of each pixel for *Image_O*, *Image_I*, image for view 1, and image for view 2, respectively. *Image_O* represent the image that viewers without the special eyeglass can see. *Image_I* represents the image that viewers without the special eyeglass cannot discern. Lum represents the normalized luminance for the given gray level.

normalized luminance Lum (D_x) for the gamma of 2.2 can be written as follows. [14]

$$\text{Normalized luminance Lum}\ (D_x) = (D_x/255)^{2.2} \quad (1)$$

From the data of the gray levels of RGB of *Image_O* and *Image_I*, the normalized luminance of RGB of *Image_O* and *Image_I* can be determined from Eq. (1).

$$\text{Lum}(D_o) = (D_o/255)^{2.2} \quad (2a)$$

$$\text{Lum}(D_I) = (D_I/255)^{2.2} \quad (2b)$$

D_O and D_I represent one of the gray levels of red, green, and blue of pixels for *Image_O* and *Image_I*, respectively. As the overlap of the image for view 1 and view 2 should be equal to the original image, sum of luminance at the pixel of the image for view 1 and view 2 had to be equal to the luminance at the corresponding pixel of *Image_O*. Hence, normalized luminance of the corresponding pixels of the images for view 1 and view 2 should satisfy the following relation.

$$\text{Lum}(D_1) = \text{Lum}(D_O)\times\ \text{Lum}(D_I) \quad (3a)$$

$$\text{Lum}(D_2) = \text{Lum}(D_O)\times\{1 - \text{Lum}(D_I)\} \quad (3b)$$

$$\text{Lum}(D_1) + \text{Lum}(D_2) = \text{Lum}(D_O) \quad (3c)$$

D_1 and D_2 represent the gray levels of the corresponding pixels of one of RGB for image for view 1 and image for view 2, respectively. Then, from the normalized luminance of the corresponding pixels of the images for view 1 and view 2, data of the gray levels of RGB of the images for view 1 and view 2 are calculated by Eq.(4).

$$Dj = 255\times(\text{normalized luminance})^{1/2.2}\ j = 1\ \text{or}\ 2 \quad (4)$$

3 Experiment

To experimentally verify the proposed concept, 3D display with the patterned retarder was used as the sample display. Pixel pitch, the resolution, and the diagonal size of the sample display were 0.485 mm, 1920 × 1080 pixels, and 42 in. Polarized eyeglass where the left and the right sides of the eyeglass were made by the same circular polarizer was also prepared. In this experiment, Spyder4Elite was used to calibrate the relation between the luminance and the gray level of the sample display to be approximately equal to the gamma of 2.2.[15]

Figure 5(a) illustrated the example of the original image, *Image_O*. Figure 5(b) illustrated the example of the information image, *Image_I*, that the viewer with the special glass can see, overlapped with *Image_O*. *Image_I* was selected to

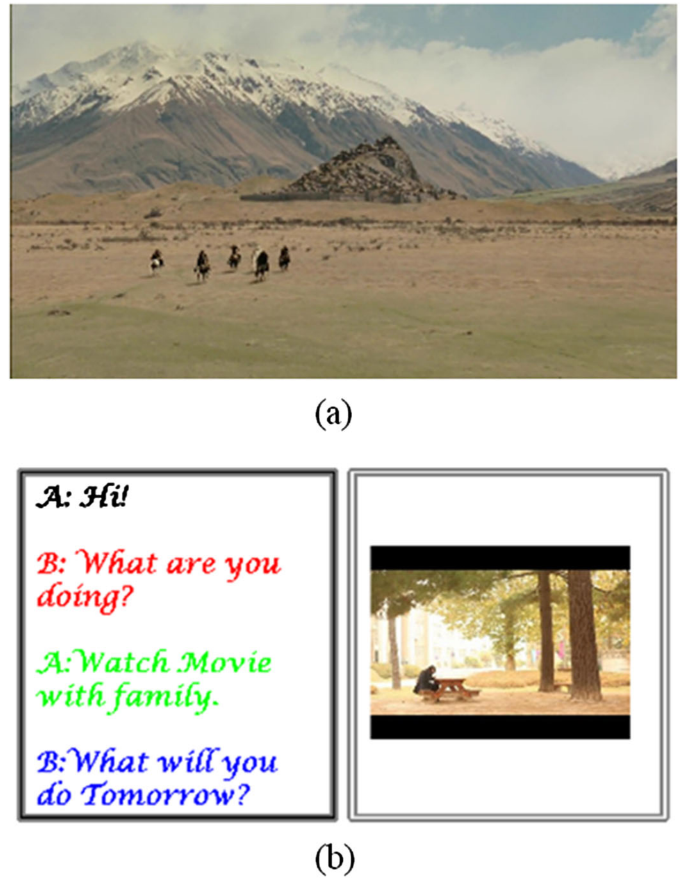

FIGURE 5 — Example of (a) *Image_O*: original image and (b) *Image_I* : information image.

consist of characters of black and three primary colors on the left side and a photo of the scenery on the right side.

Images for view 1 and view 2 were generated by the calculation scheme of Fig. 4. Matlab™ S/W was used to handle the image processing.[16] Images for view 1 and view 2 were used as the input data for two views for the selected 3D sample display. The sample display was observed without the special eyeglass and through the special eyeglass. The special eyeglass blocks the light coming from the horizontal even lines, which was assigned to the image for view 2.

4 Results and discussion

The generated images for view 1 and view 2 were shown in Fig. 6(a) and (b). The patterned retarder of the sample display consisted of the horizontal lines of the alternating direction of the retardation axes. Therefore, the images for view 1 and view 2 were alternatively shown on the odd and even horizontal lines of the sample display. Texts of red, green, and blue in *Image_I* of Fig. 5(b) changed into texts of cyan, magenta, and yellow in the image for view 2 of Fig. 6(b). The scenery on the right side of *Image_I* of Fig. 5(b) became the negative of the scenery in Fig. 6(b). The overlap of images for view 1 and view 2 would cancel the luminance

FIGURE 6 — Images for view 1 and view 2 generated by the calculated scheme of Fig. 4.

difference because of *Image_I* such that the viewers without the special eyeglass could only see *Image_O*.

Photos of the sample display were taken at the various positions of the special eyeglass in order to compare the image observed with and without the eyeglass. Photo of Fig.7(a) was taken without the special eyeglass and corresponded to the image seen by the viewer without the special eyeglass. Photo of the sample display inside the frame of the special eyeglass of Fig. 7 (c) corresponded to the image seen by the viewer wearing the special eyeglass. In photo of Fig. 7(b), the eyeglass partially covered the display area and the information image *Image_I* can be observed only inside the frame of eyeglass.

The experimental result accorded with the proposal that image for view 1 of Fig. 6(a) were seen only by the viewer wearing the special eyeglass, while *Image_O* of Fig.5 (a) were seen by the viewer without the special eyeglass. Image for view 1 appeared such that the *Image_I* was transparently overlapped on *Image_O*. Texts or simple diagrams may be identified in the overlapped image by the viewer wearing the special eyeglass. If the complex image like the photography is used as the information image, the original image is expected to hinder to identify the information image.

Examples of calculated gray levels of images for view 1 and view 2 for the various gray levels of the original image and the information image were shown in Table 1. In the calculated

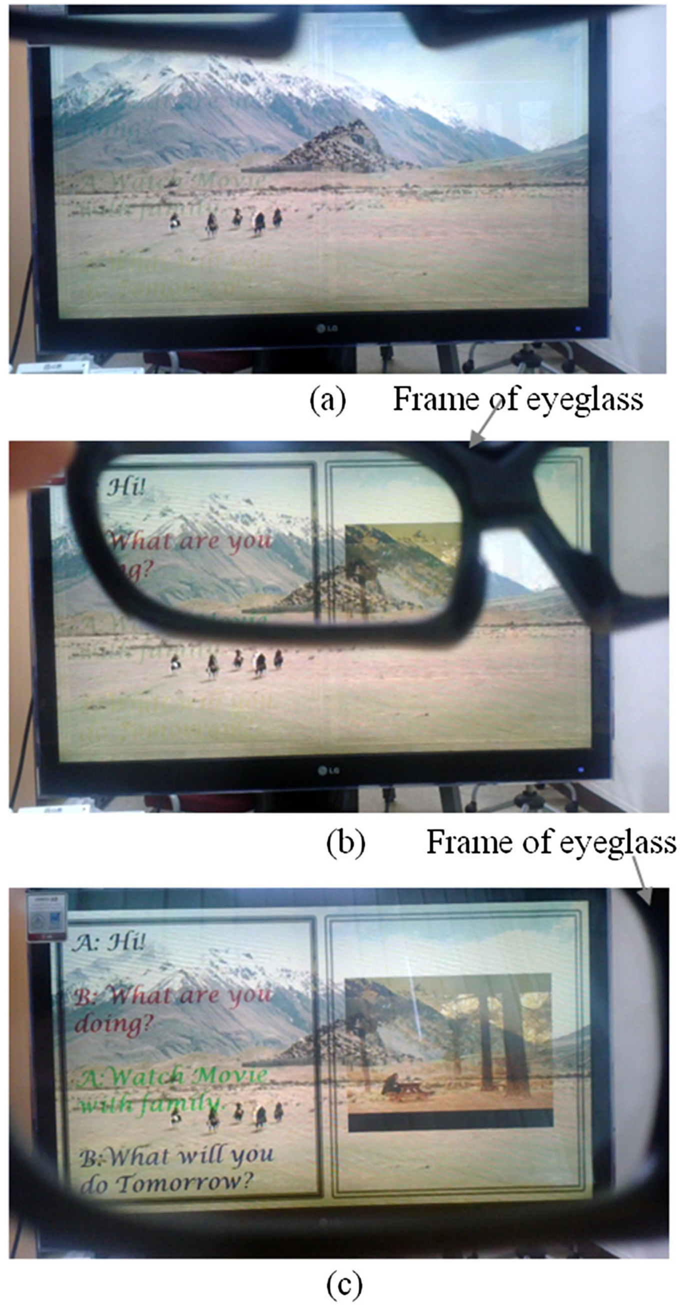

FIGURE 7 — Photo of the sample display observed (a) without eyeglass, (b) with eyeglass partially covering the display, and (c) with eyeglass.

result of Table 1, the sum of the normalized luminance of D_1 and D_2 was always equal to the normalized luminance of $D_{O.}$ In the actual display, the relation between the normalized luminance and the gray level might be deviated from Eq. (1). In that case, the sum of the normalized luminance of D_1 and D_2 would be different from the normalized luminance of $D_{O.}$ Then the viewer without the special eyeglass would perceive the existence of the information image. In photo of Fig. 7(a), the vague outline of information image can be perceived. To make the outline of the information image less visible in Fig. 7 (a), the more accurate characterization of the relation between the luminance and the gray level is required.

TABLE 1 — Examples of the calculated gray levels and luminance in the generation of images for view 1 and view 2. D_O, D_I, D_1, and D_2 represent the one of RGB gray levels of each pixel for *Image_O*, *Image_I*, image for view 1, and image for view 2, respectively. Lum represents the normalized luminance for the given gray level.

D_o	D_I	Lum(D_o)	Lum(D_I)	Lum(D_1)	Lum(D_2)	D_1	D_2
0	0	0.00	0.00	0.00	0.00	0	0
127	0	0.22	0.00	0.00	0.22	0	127
255	0	1.00	0.00	0.00	1.00	0	255
0	63	0.00	0.05	0.00	0.00	0	0
127	63	0.22	0.05	0.01	0.21	31	124
255	63	1.00	0.05	0.05	0.95	63	250
0	127	0.00	0.22	0.00	0.00	0	0
127	127	0.22	0.22	0.05	0.17	63	114
255	127	1.00	0.22	0.22	0.78	127	228
0	191	0.00	0.53	0.00	0.00	0	0
127	191	0.22	0.53	0.11	0.10	95	90
255	191	1.00	0.53	0.53	0.47	191	181
0	255	0.00	1.00	0.00	0.00	0	0
127	255	0.22	1.00	0.22	0.00	127	0
255	255	1.00	1.00	1.00	0.00	255	0

5 Conclusion

The display proposed that the viewers wearing the special eyeglass can observe the hidden image. The proposed concept was experimentally verified using 3D display with the patterned retarder. The effectiveness of the hiding of the additional information or image is affected by the relation between the gray level and the luminance of the selected display. The relation between the gray level and the luminance had to be accurately characterized for the generation of input signal for view 1 and view 2.

In proposed display application, the hidden information can be either private information or the information that other people do not need. Following usages may be considered. The private information can be seen at the public space only by the user wearing the special eyeglass. The subtitle for the foreign movie can be selectively seen by the viewers wearing the special glass. In that case, viewing experience of other viewers who do not need the subtitle will not be disturbed by the subtitle as they cannot see the subtitle without the special eyeglass. A personal message can be shown on TV, while a family is watching TV at the living room.

The proposed display was compatible with technologies of 3D display using the special eyeglasses. Though the special eyeglass was not different from the special eyeglass used for the 3D display, the special eyeglass was expected to be easily converted from the special eyeglass used for the 3D display.

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References

1 T. Okoshi, “3 Dimensional Image Techniques,” Academic Press: New York (1976).
2 C. van Berkel, “Image preparation for 3D-LCD,” *Proc. SPIE* **3639**, 84–91 (1999).
3 B. Javidi and F. Okano, “Three–dimensional Television, Video, and Display Technologies,” Springer: Berlin (2001).
4 J. Y. Son and B. Javidi, “Three-dimensional imaging method based on multiview images,” *J. Disp. Technol.* **1**, 125–140 (2005).
5 A. Woods, “3-D displays in the home,” *SID Inf. disp.* **25**, 8–12. (2009).
6 H. K. Hong *et al.*, “Analysis of angular dependence of 3-D technology using polarized eyeglass,” *J. SID* **18**, 8–12 (2010).
7 A. Abileah, “3-D displays – technologies and testing methods,” *J. SID* **19**, 749–763 (2011).
8 D. M. Hoffman *et al.*, “Temporal presentation protocols in stereoscopic displays: flicker visibility, perceived motion and perceived depth,” *J. SID.* **19**, 255–281 (2011).
9 H. K. Hong, “Reduction of spatially non-uniform 3D crosstalk for stereoscopic display using shutter glass,” *Displays* **33**, 136–141 (2012).
10 “3D TV Penetration ratio,” Display Search 2013 http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/120926_tv_to_drive_global_demand_for_3-d_ready_devices.asp, accessed Aug, 2014.
11 The illustrated 3D movie list, “The illustrated 3D HDTV list,” http://www.3dmovielist.com, accessed Aug, 2014.
12 S. Sechrist, “Display week 2012 review: 3-D,” *SID Inf. Disp.* **28**, 10–13 (2012).
13 J. Fridrich *et al.*, “Searching for the Stego Key.” *Proc. SPIE, Electronic Imaging, Security, Steganography, and Watermarking of Multimedia Contents VI* **5306**, 70–82 (2004).
14 D. G. Lee *et al.*, “Evaluation method of electro-optical transfer function for display devices,” *J. SID.* **18**, 913–921 (2010).
15 Datacolor Spyder4Elite, http://spyder.datacolor.com/portfolio-view/spyder4elite/, accessed Aug, 2014.
16 Matlab http://www.mathworks.com/products/matlab, accessed Aug, 2014.

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