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# Color Visual Cryptography with Stacking Order Dependence Using Interference Color

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## Abstract

Visual cryptography is an encryption method that shares a secret image through several encrypted images. General visual cryptography has no stacking order dependence, and only one image can be decoded regardless of stacking order of encrypted images. We previously reported a color visual cryptography using interference color (or polarization color) of retarder films. The interference color changes depending on the stacking order of retarder films. In this paper, we propose and develop a color visual cryptography that displays two images by changing stacking order of retarder films.

## Keywords

Visual Cryptography, Polarizer, Interference Color, Birefringent Material

## 1. Introduction

In recent years, various optical encryption methods and devices have been proposed for information security [1]-[7]. Visual cryptography is an encryption method that shares a secret image through several encrypted images. The basic algorithm of visual cryptography was reported by Naor and Shamir [8] and Kafri and Keren [9]. This algorithm is considered to be very effective for encrypting image because it is impossible to estimate or determine the secret image from each separated key image. In conventional visual cryptography, each key image (share) is a random distribution of black-and-white subpixels. By copying shares to transparencies and stacking them, the secret image can be observed.

Many types of visual cryptography have been proposed [8]-[17]. Conventional visual cryptography is based on spatial coding that requires multiple subpixels to modulate light intensity. Therefore, image quality of the decoded image is reduced. This problem is more serious in visual cryptography for color images. Visual cryptography for color images has been reported [13] [14] [15] [16]. A color visual cryptography technique is useful for various applications, but more multiple color subpixels are needed. For example, to encryption color images through two shares, each pixel is composed of at least one red, one green, and one blue subpixel. To represent black, the minimum number of subpixels is six, where each pixel is composed of one red, one green, one blue, and three black subpixels [14]. Polarization encoding technique is one of solutions to the reduction of image quality. This encoding technique enables the encryption of each pixel in a secret image into a corresponding single pixel in shares [17] [18]. A visual encryption device using high-order retarder films was also reported by Kowa *et al.* [17]. These techniques enable the display of only a black-and-white binary image. Improved visual cryptography for gray-level images was reported by Blundo *et al.* [18]. We previously reported a color visual cryptography using high-order retarder films [19] [20]. This visual cryptography method has no stacking order dependence. A polarization encoding technique with stacking order dependence is reported by Imagawa *et al.* [21], but the decoded image can only be displayed as a gray-level image. In this paper, we propose a color visual cryptography device with stacking order dependence using interference color of high-order retarder films. Proposed visual cryptography does not reduce image quality of decoded images as the conventional polarization encoding technique. Also, it is possible to display two images in color that has been impossible in conventional polarization encoding technique. We describe the principles of the interference color display with stacking order dependence using polarization films in Section 2. In Section 3, we describe the design of the visual cryptography method with stacking order dependence.

## 2. Principles of Interference Color Display with Stacking Order Dependence

In this section, the principles of interference color displays with stacking order dependence are described. **Figure 1** shows the optical composition to for displaying interference color. **Figure 1(a)** shows a general optical composition for displaying interference color. A retarder film is inserted between two crossed polarizers such that the retarder axis of the retarder film is 45˚. **Figure 1(b)** shows the calculated interference color chart using CIE standard illumination D65. Various colors can be displayed by changing the retardation x of the retarder films. **Figure 1(c)** shows the proposed optical composition for displaying interference color. Three retarder films are inserted between two crossed polarizers such that the retarder axes of the retarder films are 135˚, 0˚, and 45˚, respectively. **Figures 1(d)-(g)** show the calculated interference color chart using CIE standard illumination D65. Various colors can be displayed by changing the retardation x of the retarder film, but it also depends on the retardation y. The best retardation y was 140 nm in this simulation, because various colors can be displayed by changing the retardation x. The calculated interference color shown in **Figure 1(d)** is almost the same as the interference color of the general optical composition shown in **Figure 1(b)**. We fix the value of retardation y to 140 nm in our experiment.

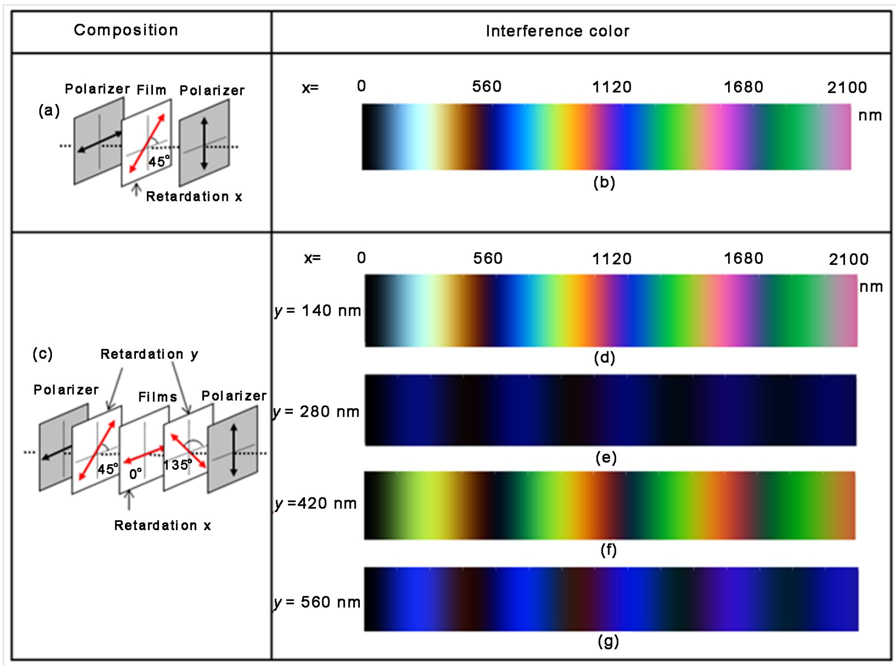



**Figure 1.** Optical composition and interference color. (a) General optical composition for displaying interference color; (b) Interference color chart of a general optical composition; (c) Proposed optical composition for displaying interference color; (d) Interference color chart of the proposed optical composition when the retardation y is 140 nm; (e) Interference color chart of the proposed optical composition when the retardation y is 280 nm; (f) Interference color chart of the proposed optical composition when the retardation y is 420 nm; (g) Interference color chart of the proposed optical composition when the retardation y is 560 nm.

Figure 2 shows the composition the of interference color display with stacking order dependence. Four retarder films (films 1, 2, 3, and 4) are inserted between two crossed polarizers such that the retarder axes of the retarder films are 135˚, 0˚, 45˚, and 0˚, respectively. The composition shown in Figure 2(a) is almost the same as that shown in Figure 1(c). The only difference is film 4. The retardation of films 1 and 3 are 140 nm. In this composition, the displayed interference color only depends on the retardation of film 2. By changing this retardation, the interference color changes as shown in Figure 1(d). No interference color changes by changing the retardation of film 4. We note that image 1 consists of films 1 and 2, and image 2 consists of films 3 and 4. By changing the position of images 1 and 2, as shown in Figure 2(b), the displayed interference color changes. In this case, the interference color changes because the retardation of film 4 changes, as shown in Figure 1(d). No interference color changes by changing the retardation of film 2. To investigate the color variation obtained by this technique, we designed a color model for the polarization images. We used two types of retarder films with retardations of 140 and 560 nm. Conventional $\lambda/4$ retarder films are used for the 140 nm retarder films, and conventional $\lambda$ retarder films are used for the 560 nm retarder films. The wavelength dispersion of the $\lambda/4$ and $\lambda$ retarder films is the same, and the image size was 100 × 100 mm$^2$.

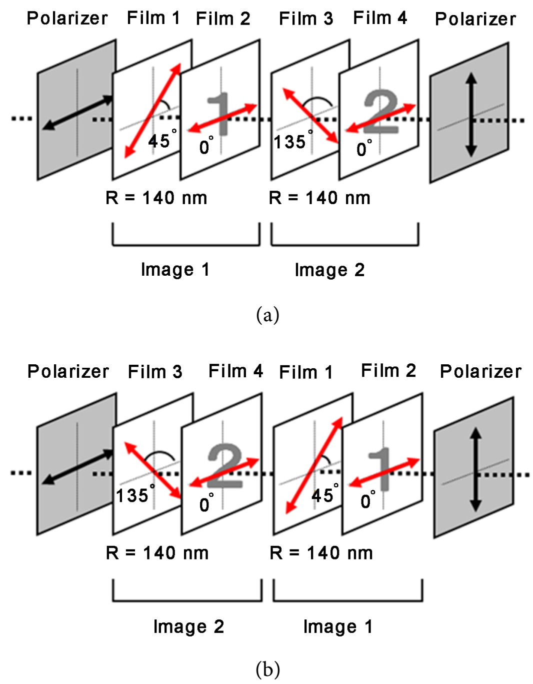
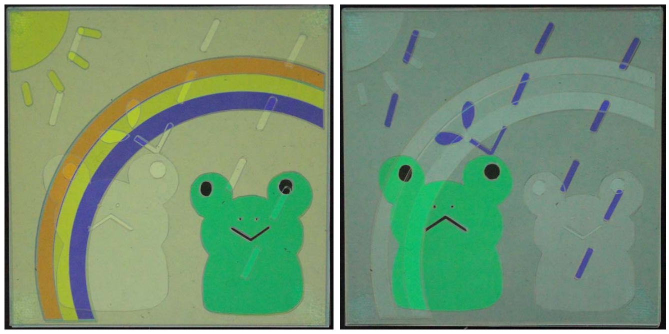



**Figure 2.** Composition of the interference color image with stacking order dependence. (a) Image 1 and 2; (b) Image 2 and 1.

Films 1 and 3 were fabricated using a $\lambda/4$ retarder film. The slow axes of these retarder films are set to 45˚, and 135˚, respectively. Film 2 and film 4 were fabricated by stacking retarder films. The slow axes of these retarder films were set to 0˚ and 90˚, respectively. The slow axes of 90˚ were used to compensate for the film retardation. The total phase retardations of the colors used in these images are 0, 140, 280, 420, 560, 840, and 1260 nm. A white backlight (KLV-7000, Hakuba) was used to view the image. Figure 3(a) and Figure 3(b) show the polarization color image with stacking order dependence.

## 3. Design of Visual Cryptography with Stacking Order Dependence

In this section, we show the proposed method for color visual cryptography with stacking order dependence. In Section 2, we presented the method for designing the interference color image with stacking order dependence. To encrypt the original image, we need to create share images to. Figure 4 shows a simple example of a color visual cryptography algorithm with stacking order dependence. Images 1 and 2 are shared through two shares (shares 1 and 2). Share 1 is composed of three films, (film 2', a retarder film with a retardation of 140 nm, and film 1). Share 2 is composed of three films (film 1', a retarder film with a retardation of 140 nm, and film 2). Various colors can be displayed by changing the phase retardation of the retarder films, and the colors can be changed by adding or subtracting the phase retardations. Image 1 is shared through films 1 and 1', and image 2 is shared through films 2 and 2'. For the composition shown in



(a) (b)

**Figure 3.** Polarization color image with stacking order dependence. (a) Image 1 and 2; (b) Image 2 and 1.

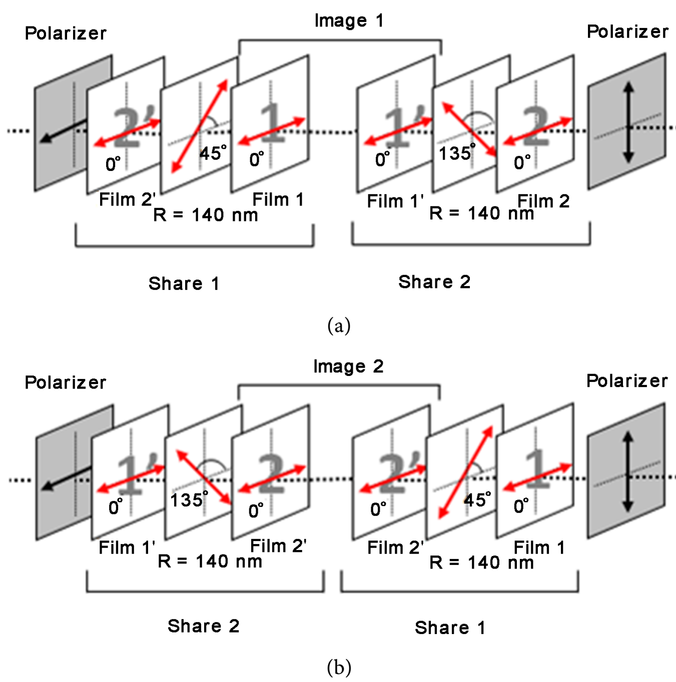



**Figure 4.** Composition of the polarization color visual cryptography with stacking order dependence. (a) Share 1 and 2; (b) Share 2 and 1.

Figure 4(a), the interference color changes according to the additional retardation of films 1 and 1', as shown in Figure 1(d). No interference color changes by changing the retardation of films 2 and 2'. By changing the stacking order, as shown in Figure 4(b), the interference color changes according to the additional retardation of films 2 and 2' as shown in Figure 1(d). No interference color changes by changing the retardation of films 1 and 1'.

Next, we designed a prototype of the proposed polarization color visual cryptography with stacking order dependence. Two secret images (images 1 and 2) were composed of 4-digit numbers. The image sizes were 175 × 80 mm$^2$. Image 1 is shared through two images, films 1 and 1', and image 2 is shared through two images, films 2 and 2'. Figure 5 shows the phase retardation (nm) and interference color of each film with a crossed polarizer of ±45˚. A positive number

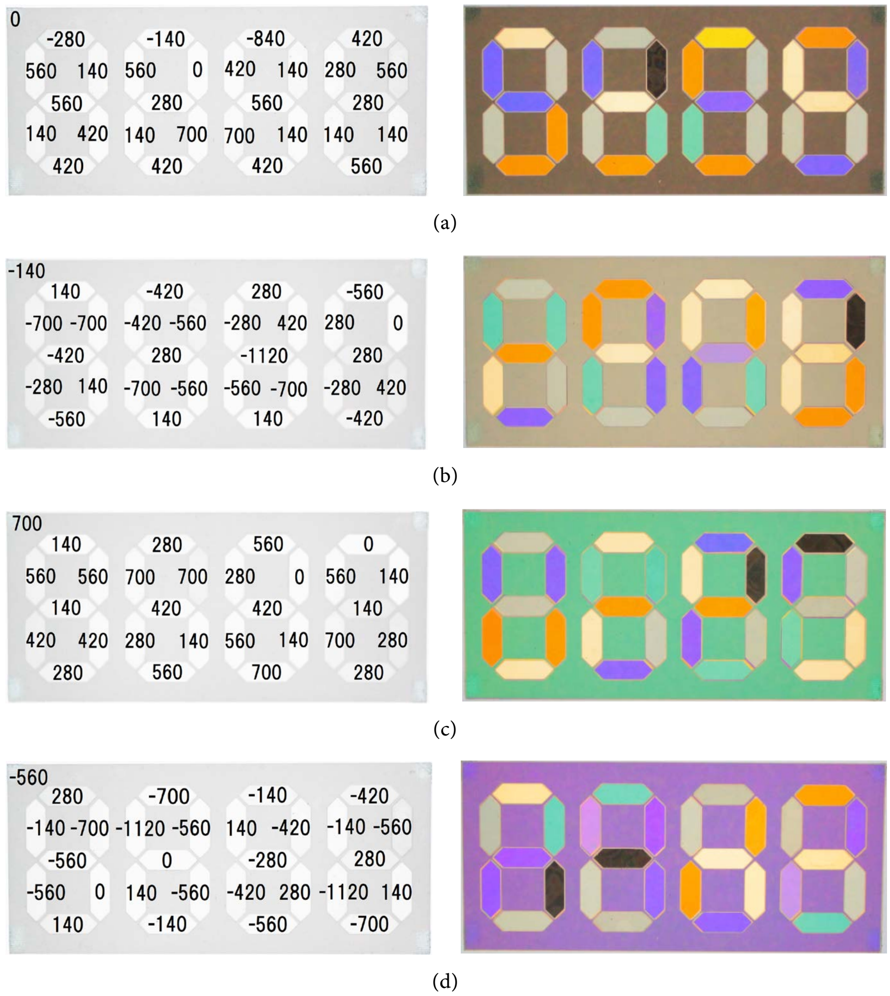
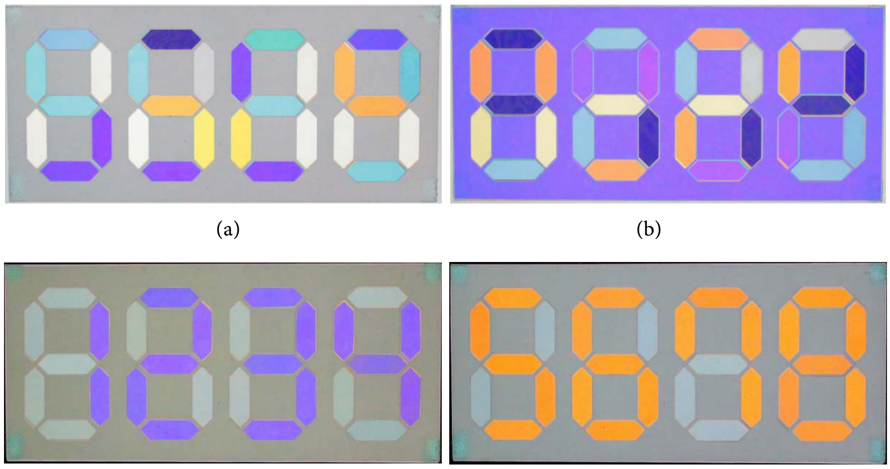



**Figure 5.** Model of polarization color visual cryptography with stacking order dependence. (a) Phase retardation and interference color of film 1; (b) Phase retardation and interference color of film 1'; (c) Phase retardation and interference color of film 2; (d) Phase retardation and interference color of film 2'.

indicates that the retarder axis is 0˚, and a negative number indicates that the retarder axis is 90˚. Four or five retarder films were used to design each film. Even if combinations of interference colors are the same before decoding, different interference colors can be displayed after decoding that depending on axes of retarder films. Also even if combinations of interference colors are the different before decoding, same interference colors can be displayed after decoding. Therefore, it is impossible that decoded images will be leaked from the interference colors of films. Shares 1 and 2, observed with crossed polarizers of ±45˚, are shown in Figure 6(a) and Figure 6(b). Share 1 is composed of three films, (film 2', a retarder film with a retardation of 140 nm, and film 1), and share 2 is composed of films (film 1', a retarder film with retardation of 140 nm, and film 2). In this case, the secret 4-digit number is not observed from each share. By stacking shares 1 and 2, as shown in Figure 4(a), the interference color changes according to the additional retardation of films 1 and 1' as shown in Figure 6(c). The blue secret number "1234" is observed. By changing the stacking order, as



(a) (b)

(c) (d)

**Figure 6.** Polarization color visual cryptography with stacking order dependence. (a) Share 1; (b) Share 2; (c) Decoded image 1; (d) Decoded image 2.

shown in Figure 4(b), the interference color changes because of the additional retardation of films 2 and 2', as shown in Figure 6(d). The orange secret number "5678" is observed.

## 4. Conclusion

We produced a color visual encryption technique in which the display image changes depending to the stacking order of encrypted images. We calculated the interference color of the conventional and proposed method. A prototype of a color visual cryptography device with stacking order dependence using interference color was developed. We need no special optical systems to observe portable encrypted images. This technique is very simple and can be applied in security and entertainment.

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