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Lenticular display with infrared watermark by modified digital halftoning techniques

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Abstract. The objective of this research is to use modified digital halftoning techniques of Amplitude Modulation (AM) and Frequency Modulation (FM) to integrate lenticular lenses with switching images and embedded infrared watermarks. Modified digital halftoning techniques have been used to compose animated graphics and the infrared watermark. The infrared watermark consists of varied combinations of AM/FM or FM/FM halftone dots in black/cyan, magenta and yellow inks. Since the carbon material in black ink can absorb infrared light, the hidden watermark becomes visible under infrared detection. Using a lenticular lens, the image-switching effect can be achieved by viewing from different orientations. The results show that FM/FM halftone dots have a better performance in implementing a lenticular display with both image-switching features and hidden watermarks that can be observed under infrared light. The technique developed in this research can provide value-added applications for anti-forgery and product protection.

1. Introduction

With the rapid progress in imaging and display devices, requirements of the integration of multimedia elements, such as texting, images, sound, and animation, are continuously addressed by both academia and industry. Displays of still images and animated graphics have been very promising, and there has been a growing interest in lenticular image displays over the last decade, due to their wide range of applications [1]. Lenticular lenses can create different effects on displayed images, such as flips, zooming, and morphing, etc. [2]. In recent years, as the improvement of digital duplication techniques, copyright and brand protection, have become an important issue, multiple anti-counterfeiting features have been constructed, such as watermarks, using digital halftoning techniques and the characteristics of ink/substrate materials.

In respect to material characteristics in near infrared light, the inks of cyan (C), magenta (M) and yellow (Y) are transparent under infrared light, while carbon black (K) has a maximum absorbance of infrared light [3]. This demonstrates that the hidden information of a watermark can be observed and verified under infrared light. The infrared watermark design can be extended to double independent information at the same location. Different messages can be observed in normal light and infrared light, respectively. When trying to make a copy, the message in infrared is lost [4].

With regard to digital watermarks and infrared techniques, the National Printing Bureau in Japan issued a halftoning technique in 2004, named ImageSwitch®. The principle of this technology is to combine primary and secondary screens, and also to use a special arrangement of optical inks to encode an image under a cover image. However, the distribution of black dots may hinder the tone of cover images. For this reason, anti-counterfeiting features could usually

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only be applied to a limited portion of the image [5]. In 2012, CMYKIR was proposed using an optimal regression model on the basis of color tone measurement for the visual and infrared spectrum. It also presents the design for the printed postage stamp, which contains double information in the visible and infrared spectrum area [6].

A watermark with modified hybrid halftone dots is a technique that composes halftone dots by both Amplitude Modulation (AM) and Frequency Modulation (FM). Different patterns of the halftone dot arrangement can overcome sampling requirements of duplicating equipment, and makes the hidden watermarks emerge after duplication [7]. Scrambled Indicia® is patented by the Graphic Security Systems Corporation, and it manipulates images to make their encoded information unreadable to the naked eye, and non-copyable by current color copiers and digital scanners. When printed, the images are decoded through a simple decoder lenticular lens, allowing the viewer to see the encoded images [8]. Jura JSP Ltd developed line phase modulation, which is decoded by means of a lenticular screen. The carrier screen is phase modulated to create the hidden image, while line width modulation serves the creation of a visible image [9]. In 2013, the latest version of the United States $100 bill was equipped with hundreds of thousands of micro lenses that change the image from 100's to liberty bells within the ribbon, depending on how the bill is positioned. Another group introduced content-adaptive lenticular prints which jointly optimize both lens configuration and static light field content, and achieve apparent increases in spatial and angular resolution [10].

Previous research has not combined lenticular displays with image switching and infrared watermarks. By integrating these two techniques, the visual performance of a product can present an image switching effect, and the human eye cannot perceive the hidden information. The hidden infrared watermark allows combination with a 2D-barcode, which intensifies the capacity of product information and the feature of anti-counterfeiting. By integrating lenticular displays with image switching and infrared watermarks, it is able to enhance the value of products and create the possibility of multi-disciplinary value-added applications. Therefore, the purpose of this research is to integrate the infrared 2D-barcode watermark, by modified digital halftoning and animated graphics, with the lenticular lens.

2. Methods

Figure 1 shows a schematic diagram of the research approach. Two classic cover images are interlaced into one image with hidden 2D-barcode watermarks for lenticular lens displays and infrared detection. Digital halftoning techniques have been used to make both animated graphics and infrared watermarks composed of halftone dots by both Amplitude Modulation (AM) and Frequency Modulation (FM). A density calibration chart is constructed to adjust the hiding effect, and the watermark is designed as a form of 2D-barcode. Digital halftoning techniques, interlaced image formation, and infrared watermarks are described as follows.

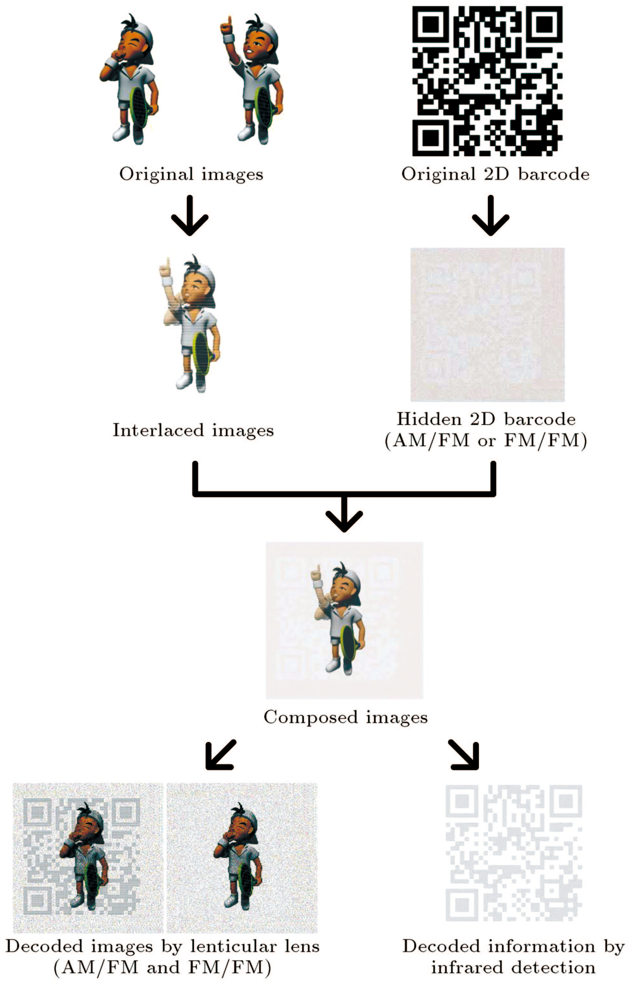

Figure 1. The schematic diagram of the research approach.

2.1. Digital halftoning

Digital halftoning can be divided into two major categories: ordered dithering and error diffusion. The algorithm of Amplitude Modulation (AM) dots is ordered dithering [11]. In Eq. (1), a grayscale image, $x(i,j)$, is input to convert its original grayscale value into value $y(i,j)$. M_1 and M_2 represent the height and width of the threshold matrix:

$$y(i,j) = M_1 \times M_2 \times \left(1 - \frac{x(i,j)}{255}\right). \tag{1}$$

According to Eq. (2), $T(i,j)$ is the threshold matrix with size M_1 by M_2, and it can convert the individual pixels of value, $y(i,j)$, into 1 s or 0 s. It can control the printer to ink or not to ink, and $z(i,j)$ is the output halftone image:

$$z(i,j) = \begin{cases} 1, & y(i,j) \geq T(i,j) \\ 0, & y(i,j) < T(i,j) \end{cases} \tag{2}$$

On the other hand, the algorithm for Frequency Modulation (FM) dots is based on Floyd-Steinberg Error Diffusion [12]. After inputting the grayscale value of the original image, $G(i,j)$, and comparing it with the threshold values, T, the binary value, f, (by Eq. (3)) and error will be obtained. Then, the error will be diffused to the neighboring pixels, and a proper matrix is chosen to distribute the weightings of error diffusion, as shown in Eq. (4):

$$f(i,j) = \begin{cases} 1, & G(i,j) \geq T \\ 0, & G(i,j) < T \end{cases} \tag{3}$$

The FM halftone dots formulated by error diffusion are using single pixels as the basic processing unit. Therefore, its resolution is higher than an AM halftone dot, whose dithering is carried out using the size of the threshold matrix as the basic unit:

$$\frac{1}{16}\begin{bmatrix} 0 & 0 & 0 \\ 0 & -16 & 7 \\ 3 & 5 & 1 \end{bmatrix}. \tag{4}$$

2.2. Interlaced image formation

Image-switching animation is carried out for three pairs of images (in Figure 2) from computer graphics (Lu's images), monochrome graphic design (logo images) and photographs (concentric images). Classic Lu images, including "Kiss Fingers" and "Point to the Sky" from the Taiwanese tennis player Yen-Hsun Rendy Lu, who was a 2010 Wimbledon quarter-finalist, are used as the cover images. The "logo images" are from the logo of the Department of GraphicArts and Communications at NTNU (National Taiwan Normal University), which symbolizes "keep moving". The "concentric images" symbolize team work with animation.

In this research, the 75 LPI (lines per inch) lenticular lens is used; it is a utility lens effective at delivering both 3D and animation effects. Two prototype images, sized 2400×2400 at 1200 dpi, are resized into 750×2400 pixels. The pixels of two images are divided into strips and the interlaced sub-images are grouped together as an image, according to Eq. (5) (shown in Figure 3):

$$\begin{aligned} & s(3+(i-1)*16:7+(i-1)*16,:) \\ & \quad = a(1+(i-1)*5:5+(i-1)*5,:), \\ & s(10+(i-1)*16:14+(i-1)*16,:) \\ & \quad = b(1+(i-1)*5:5+(i-1)*5,:). \end{aligned} \tag{5}$$

By Eq. (5), one can be aware of the lenticular lens with one pitch width of two sub-images, where s is the composed interlaced image, and a and b are the two

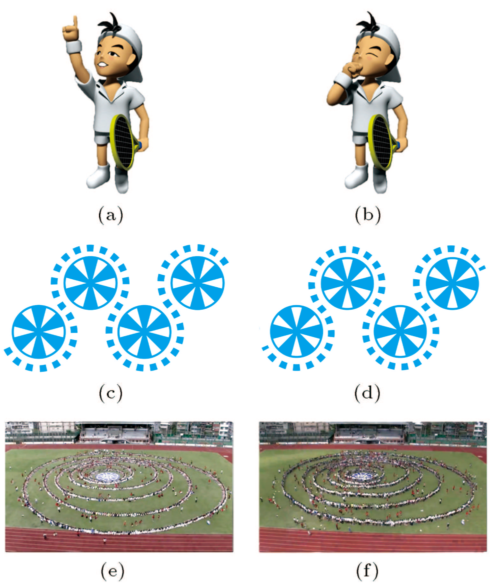

Figure 2. Three pairs of images are used in this research: (a) & (b): Lu's images; (c) & (d): logo's images; and (e) & (f): concentric images.

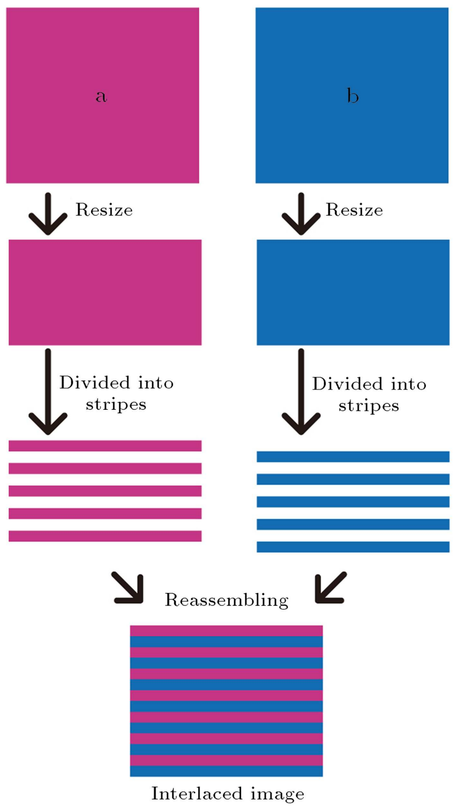

Figure 3. Interlaced sub-images are regrouped.

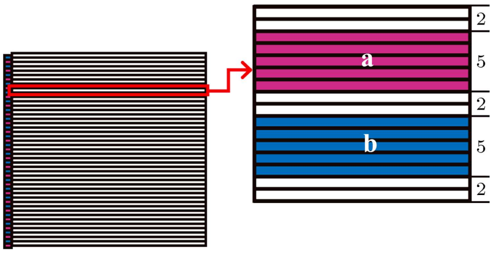

Figure 4. The width of each lenticular pitch containing two interlaced sub-images.

sub-images before division. The physical dimension is 2×2 inches. The interlaced image and the infrared watermark (AM/FM or FM/FM) are printed directly onto a paper registered to the back of a lenticular lens (Figure 4), and the lenslet isolates and magnifies a portion of the interlaced image beneath. Depending on the angle of observation, the lenticular lens runs horizontally, and a rotation of the lens creates an animation effect.

2.3. Infrared watermark

A density calibration chart is used for an infrared watermark to find the optimal hidden effect (Figure 5). The selected parameters of a density combination of black (K) ink and different cyan (C), magenta (M) and yellow (Y) inks would exhibit the same density to the human eye under visible light. This density calibration chart choses 5% AM or FM halftone dots (in K) with different percentage combinations of FM halftone dots (in CMY 2-5%). That is, there are two kinds of infrared watermark, AM/FM and FM/FM.

Figure 6 shows a schematic diagram of the composition of an infrared watermark, and the algorithm has been obtained from a logic operation in Eq. (6). The D_1 is FM dots composed of CMY inks, and D_2 is AM or FM dots composed of carbon black. After going through mask M and $\sim M$, the AM/FM or FM/FM infrared watermark is obtained as $E(i,j)$:

$$E(i,j)=(D_1(i,j)\cap M(i,j))\cup(D_2(i,j)\cap\sim M(i,j)). \quad (6)$$

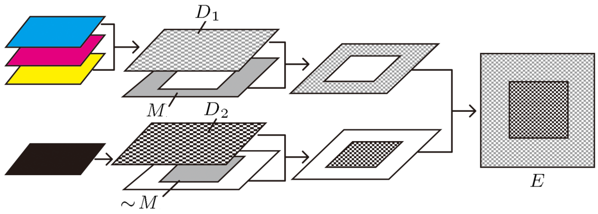

Figure 6. The schematic diagram of the composition of infrared watermark.

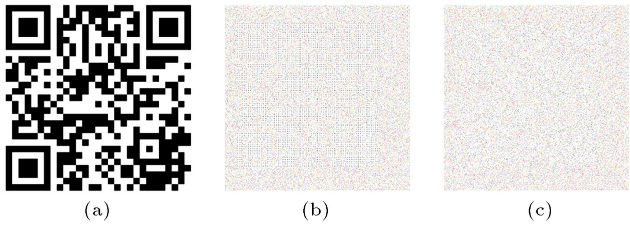

Figure 7. The 2D barcode is used to design hidden watermark: (a) Original 2D barcode; (b) hidden 2D barcode by AM/FM halftoning; and (c) hidden 2D barcode by FM/FM halftoning.

3. Results

A 2D barcode is used to design a hidden watermark. The experimental results (in Figure 7) show the original and hidden 2D barcodes using AM/FM and FM/FM halftoning techniques. The hidden 2D barcodes in Figure 7(b) and (c) can be composed with interlaced images. Figure 8 shows the digital simulation of decoded images by a lenticular lens. In this digital simulation, the decoded image is obtained by resampling at an interval of 16 pixels. The images in Figure 8(a), (b), (e), (f), (i) and (j) use AM/FM halftoning with the lenticular lens. However, the 2D barcode watermark is also enhanced. This is due to interference between the pitch of the lenticular lens and the period of AM halftone dots. The images in Figure 8(c), (d), (g), (h), (k) and (l) use FM/FM halftoning with the lenticular lens. Using FM/FM halftoning has a better hiding effect than using AM/FM halftoning.

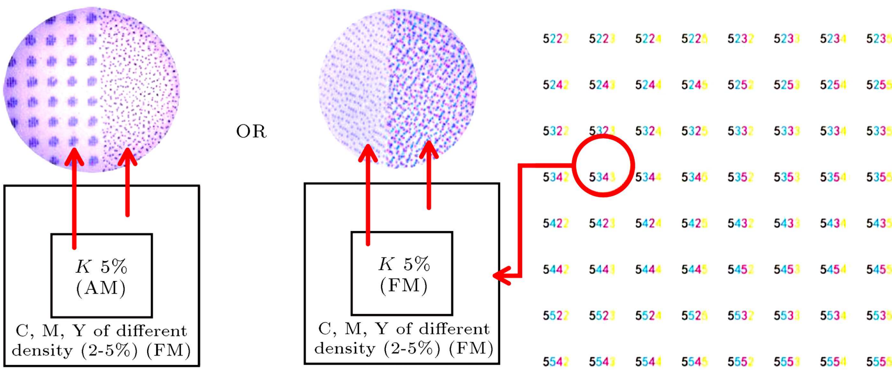

Figure 5. Density calibration charts for AM/FM and FM/FM infrared watermarks. The chart is designed for comparing 5% FM halftone dots (in K) or 5% AM halftone dots (in K) with different percentage combinations of FM halftone dots (in CMY, 2-5%).

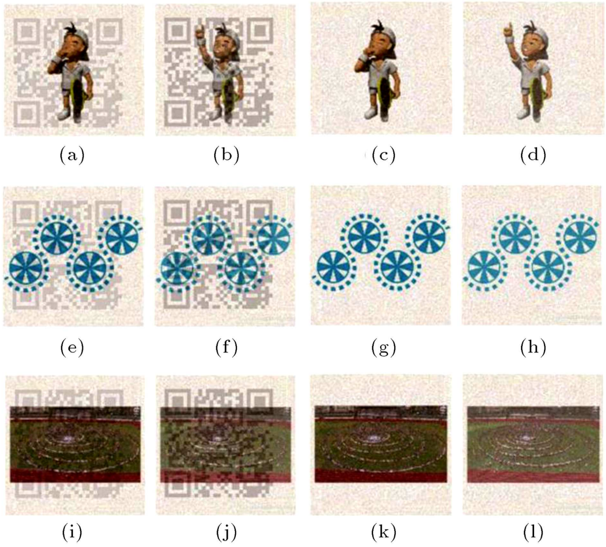

Figure 8. The simulated decoded images by lenticular lens: (a), (b), (e), (f), (i) & (j): Using AM/FM halftoning with the lenticular lens; (c), (d), (g), (h), (k) and (l): Using FM/FM halftoning with the lenticular lens. The image switching effect can be observed.

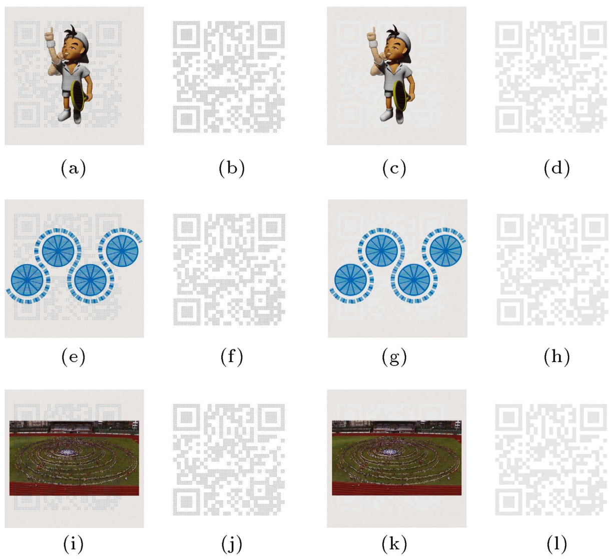

Figure 9. Digital simulation of infrared detection: (a), (b), (e), (f), (I) and (j): Using AM/FM halftoning; (c), (d), (g), (h), (k) and (l): Using FM/FM halftoning.

The experimental results in Figure 9 show the digital simulation of infrared detection with AM/FM and FM/FM watermarks. Signals from the composed image's black ink channel are extracted as the watermark. The images in Figure 9(a), (e), and (i), using AM/FM halftoning, are able to observe hidden 2D barcodes, as shown in Figure 9(b), (f) and (j). The images in Figure 9(c), (g), and (k), using FM/FM halftoning, are able to observe the hidden 2D barcodes shown in Figure 9(d), (h) and (l). The infrared detection is not sensitive to the usage of AM/FM or FM/FM halftoning.

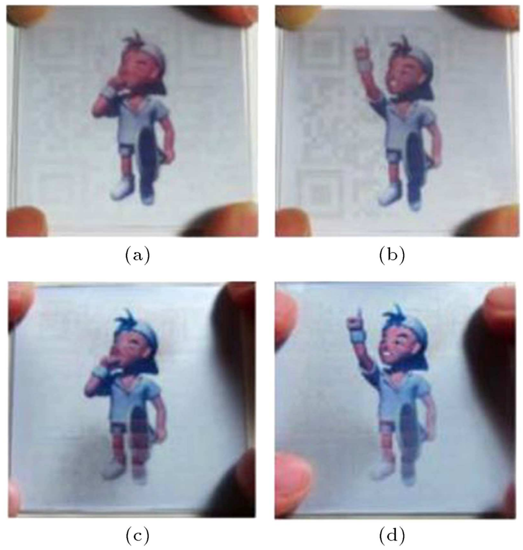

Figure 10. (a) & (b): Using AM/FM halftoning with lenticular lens, it creates "Kiss fingers" and "Point to the sky" image switching effect from different angles of observations. However, the 2D barcode watermark is also enhanced. (c) & (d): Using FM/FM halftoning with lenticular lens, it creates better image switching effect.

The experimental results in Figure 10 show the printed output of Lu's composed images. Figure 10(a) and (b) show image-switching animation with a hidden AM/FM infrared 2D barcode watermark. The animation effects using a lenticular lens create "Kiss Fingers" and "Point to the Sky" image-switching effects. However, the lenticular lens also enhances the 2D barcode watermark. This observation is consistent with the digital simulation shown in Figure 8(a) and (b). The images in Figure 10(c) and (d) show image-switching animation with a hidden FM/FM infrared 2D barcode watermark. The simulation in Figure 8(c) and (d) also indicates similar findings. Using FM/FM halftoning has a better hiding effect than using AM/FM halftoning. With the lenticular lens, the hidden 2D barcode watermark can be observed under infrared detection (shown in Figure 11). The digital simulation in Fig-

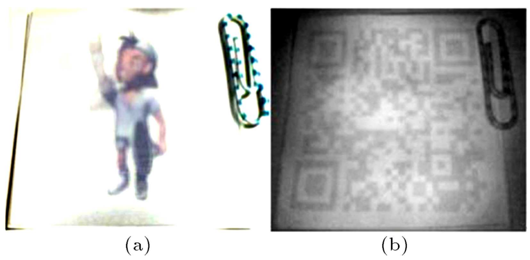

Figure 11. The image of FM/FM infrared watermark overlapped with lenticular lens: (a) In normal light, the image-switching animation can be observed; and (b) 2D barcode can appear under infrared detection.

ure 9(c) and (d) also predicts the infrared detection. It is better to adopt the FM/FM infrared watermark for product design because the watermark can be hidden under normal light, image switching can be observed by the lenticular lens without interference, and the watermark can be detected by infrared light.

4. Conclusion

This study successfully implements a lenticular display with image switching and infrared watermarks by modified digital halftoning techniques. The methods we propose in this study are not only to create animation effects combined with infrared watermarks under infrared detection, but also to open a new paradigm for the integration of meaningful animated 2D texts/graphics using the human eye and an infrared-detectable watermark. The infrared watermark, using a properly-designed FM/FM halftoning technique, shows a better performance. Its target is to secure the product against counterfeiting. The proposed method would have enormous potential in anti-forgery technologies and product value-added applications.

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Biographies

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