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A new displaying technology for information hiding using temporally brightness modulated pattern

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***Abstract* -- We propose a new display system technology that can hide secret information behind a displayed image, while simultaneously satisfying both high invisibility and readability requirements. The hidden information is a kind of binary image including characters, and various kinds of patterns, i.e., quadratic residue (QR) codes. This technique uses a temporally bright modulated invisible pattern in a moving image, or video. Frame images over some periods are summed up when read out, enhancing the contrast of the invisible pattern to make it visible. We also propose a new method to solve an issue that occurs due to asynchronous operations of the display and video camera, which is a technique that was achieved by using time shift sampling. The hidden binary image could be read out according to experiments that we conducted to confirm the results. Moreover, the patterns used in this technique were decidedly invisible when laid behind the main images, which suggested the proposed technique was highly feasible in practical applications according to this confirmation.**

***Index Terms*— information hiding, flat panel display, moving picture, video camera.**

I. INTRODUCTION

Techniques of hiding information in images have been studied in the last two decades by many researchers. Their motivation has varied in these kinds of studies. They have mainly been done to protect the copyright of digital content using digital watermarking [1]–[6]; however, studies with new kinds of motivation have recently also actively progressed [7], [8]. There are various styles of reading out hidden information from digital images. It is directly read out by digital signal processing with image data in conventional digital watermarking. However, some new applications use digital cameras, i.e., the digital image that invisibly contains information inside itself is first captured with a digital camera, and then the information is read out from the captured image by digital processing. We previously proposed a new application using a digital camera that captured an image projected onto a real object by a projector [9]–[11]. We used a spatially modulated invisible fine pattern as a watermark. This technique was for an image captured with a still camera and it could be used to protect the portrait rights of a real object.

We also studied a technique that hid a temporally modulated invisible pattern in a moving image projected onto a real object [12]. A technique that uses an invisible code by utilizing the time division of a frame period using a DLP projector has been studied. However, it needed a high-speed camera and cameras intended for consumers could not be used.

This paper presents a new technique that reads out hidden information in a displayed image on a large flat panel display (FPD) such as that for digital signage. This technique also uses a temporal modulated invisible pattern for moving images and when reading them out, frame images over some periods are added up to raise the contrast of the invisible pattern so as to make it visible. This technique enables us to make use of video cameras that have been designed for consumers. The frame periods of video cameras are usually not synchronized with those of the display even if their frame frequency is the same; therefore, the contrast in the invisible pattern cannot be enhanced simply by adding up frame images. We tried a method of time shift sampling to solve this problem. This paper also describes the evaluation of the technique we carried out through experiments.

II. BASIC CONFIGURATION AND CONCEPT UNDERLYING PROPOSED TECHNIQUE

A. Basic configuration and principle behind proposed technique

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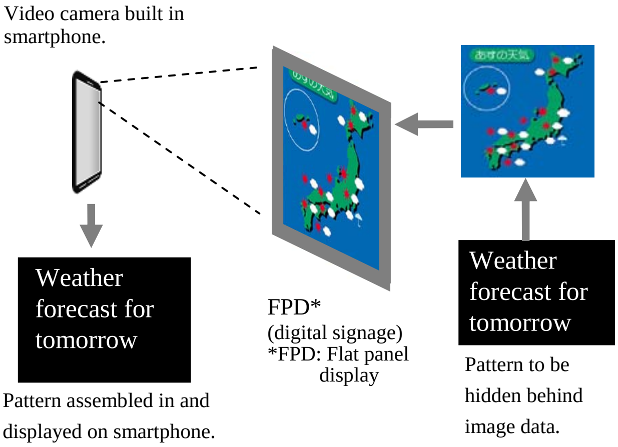

Fig. 1. Basic concept and configuration for proposed technique.

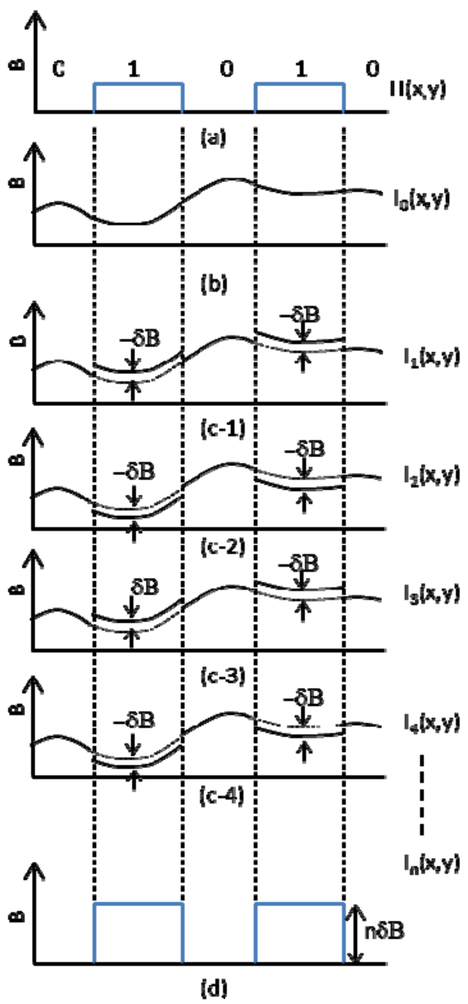

Fig. 2. How to regenerate visible image information pattern from hidden information obtained from captured image.

Figure 1 outlines the basic configuration and concept underlying the proposed technique. The binary image is hidden in an original image displayed on an FPD. The video camera captures the image on the FPD as a moving picture. The invisibly hidden binary image is abstracted from the captured image by image processing.

Figure 2 illustrates how the binary image is hidden in the original image and abstracted from the image. Each graph in Fig. 2 indicates the brightness distribution in the images; here, the vertical axis indicates the brightness and the horizontal axis indicates the position on the FPD. Although it has been drawn one-dimensionally for the sake of simplicity, it is actually two-dimensional. The (a) in Fig. 2 indicates the binary image to be hidden, which is labeled H(x,y). Figure 2 (b) indicates the original image, $I_0(x,y)$, displayed on the FPD. The original image is modulated by H(x,y), as shown in Figs. 2 (c-1)–(c-4). These images indicate successive frame images. Modulation with H(x,y) is conducted as follows. The brightness of the original is increased for odd-numbered frames by δB for the area where H(x,y)=1. The brightness of the original image for the even-numbered frames, on the other hand, is decreased by δB where H(x,y)=1.

As δB is very small, the binary image in the original image is hard to perceive. Moreover, since $I_0(x,y)$+δB and $I_0(x,y)$-δB arrive in an alternating sequence, human vision perceives brightness as their average, $I_0(x,y)$, and this also makes it hard to perceive the binary image.

After the images displayed on the FPD are captured with a video camera, successive frame images are summed up over *n* frames as:

$$S(x,y) = \sum_{j=1}^{n/2} \{I_{2j-1}(x,y) - I_{2j}(x,y)\}, \qquad (1)$$

where $I_{2j-1}(x,y)$ indicates an odd-numbered frame and $I_{2j}(x,y)$ indicates an even-numbered frame. Even-numbered frames are summed up by changing the sign, as can be seen from Eq. 1. The original image is completely canceled out in the summed up image, $S(x,y)$, which is achieved by summing up frame images, for this reason. However, changes due to modulation δB are accumulated over *n* frames and it becomes *n*δB. As a result, the hidden binary image appears to be visible.

B. Time shift sampling method

Since the frame period of the video camera is not synchronized with that of the display, if the frame period of the video camera is shifted by a half-period of the frame from that of the display, each frame image captured with the video camera equally contains $I_0(x,y)$+δB and $I_0(x,y)$-δB. That is the worst case because changes due to modulation δB are canceled out and as a result, the hidden binary image cannot be read out.

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Figure 3 illustrates how the time shift method can solve the problem of asynchrony between the display and video camera mentioned above. Figure 3 (a) illustrates the brightness of a pixel of a displayed image modulated by δB. The horizontal axis indicates the time and one division indicates a frame period. It uses two frames as a unit period, as shown in Fig. 3. The brightness of the captured image with the video camera is shown in Figs. 3 (b-1) and (c-1). This technique divides frame images into two groups of frames, i.e., odd- and even-numbered frame groups and frame images are summed up for each group. The hatched frames in Figs. 3 (b-1) and (c-1) are used in summing up for each group. Figures 3 (b-2) and (c-2) provide the accumulated values as a result of summing up for each group. If we sum up using the frames in Fig. 3 (b-1), changes due to modulation with δB are canceled out and they are not accumulated for the signal in Fig. 3 (a). However, if we use the frames in Fig. 3 (c-1), they are accumulated and as a result, the hidden pattern is abstracted as a visible one. Since there is no way of knowing which group is best in advance, we first obtain both summed up images using the two groups of (b-1) and (c-1) in Fig. 3, and we then chose the one that has the highest contrast.

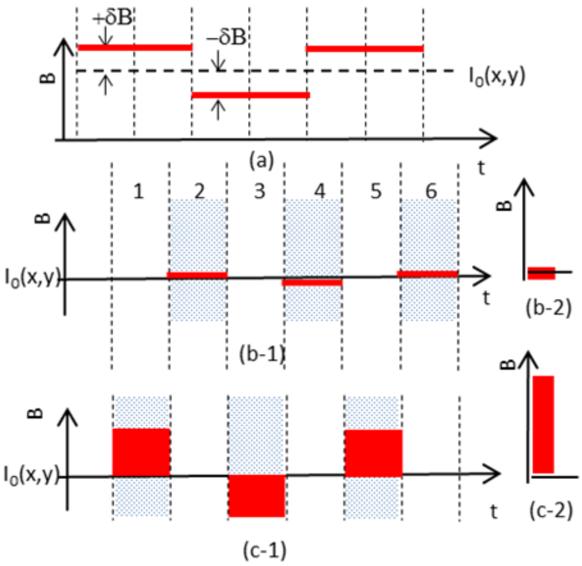

Fig. 3. Proposed phase shift method.

III. Evaluation

A. Method

We conducted experiments to demonstrate the feasibility of the technique we propose.

Figures 4 (a) and (b) are an original image displayed on an FPD and a binary image pattern hidden in the original image when it was displayed on the FPD. Each of the two images has a resolution of 1280 by 1024 pixels. The binary image pattern was hidden in only the B-component image of the original image.

(a) Original image. (b) Binary image pattern hidden behind original image data.

Fig. 4. Images used in experiments

We produced video images that invisibly contained the patterns in Fig. 4(b) with the method described in Section II. The brightness of the B-component in the pattern embedded pixels was modulated by δB. We changed δB from one to twenty as experimental parameters. Figure 5 shows the frame images modulated by a δB of twenty. The four images from top to bottom are successive frame images. Images in the left column are color frame images, and those in the right column are the B-component images. We used two frames as a unit period, as shown in Fig. 3. The first and second frame images were modulated positively, and the third and fourth frame images were modulated negatively by the pattern. These figures have gray-level values whose maximum is 255.

We subjectively evaluated whether the pattern was invisible to people who had normal or corrective-to-normal visual acuity. The subjective evaluation was carried out with ten students from the Kanagawa Institute of Technology using a set of video images that were modulated by the pattern. The subjects were in front of a display at a distance of 50 cm, and they looked at the video image for 10 s. Each subject was tested once under the same conditions.

We used a 24-inch liquid crystal display (LCD) with 1920 x 1200 pixels as an FPD. We used a video camera to save moving images with 1280 x 720 pixels using Motion-JPEG encoding.

The number of frames used for summing up, *n*, ranged from 16 to 30. The captured images were processed by using Eq. 1, as was explained in Section II.

Frame No.	Color image	B-component image
1		
2		
3		
4		

Fig. 5. Examples of frame images modulated by pattern (δB=20)

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(a) Image modulated by δB

(b) Image captured with video camera

Fig. 6. Examples of resulting images (δB=4)

B. Results and discussion

Figure 6 has examples of the resulting images. Figure 6 (a) is an image modulated by a δB of four and Fig. 6 (b) has an image captured with the video camera when it was exhibited on the display. No hidden images can be seen in either image.

Figure 7 shows the results obtained from the subjective evaluation for invisibility, which indicates the dependence of invisibility on δB. Invisibility is indicated by the percentage of the number of subjects who did not perceive any pattern from the entire number of subjects. The closed circles in the figure correspond to the invisibility of the pattern modulated by δB. It can be seen from Figure 7 that invisibility decreases with δB. None of the ten subjects could perceive any patterns for δB under nine. That meant that invisibility remained constant at 100%.

Figure 8 (a) has a summed-up image that was produced with the procedure explained in Section II. The number of frames used for summing up was 30. The hidden pattern was abstracted in the image produced in one of both ways with enough contrast to perceive it. Figure 8 (b) has an image generated by binarizing the image in Fig. 8 (a) by using the threshold value of 20, and was processed with a median filter to remove noise. It can be seen that the hidden binary image can be read out.

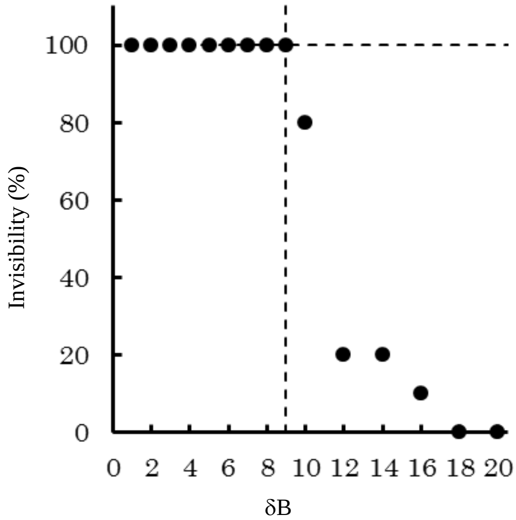

Fig. 7. Experimental results on invisibility of pattern

(a) Summed-up image

(b) Binary image pattern regenerated from summed-up image.

Fig. 8. Image pattern regenerated from modulated image data (δB=4, n=30).

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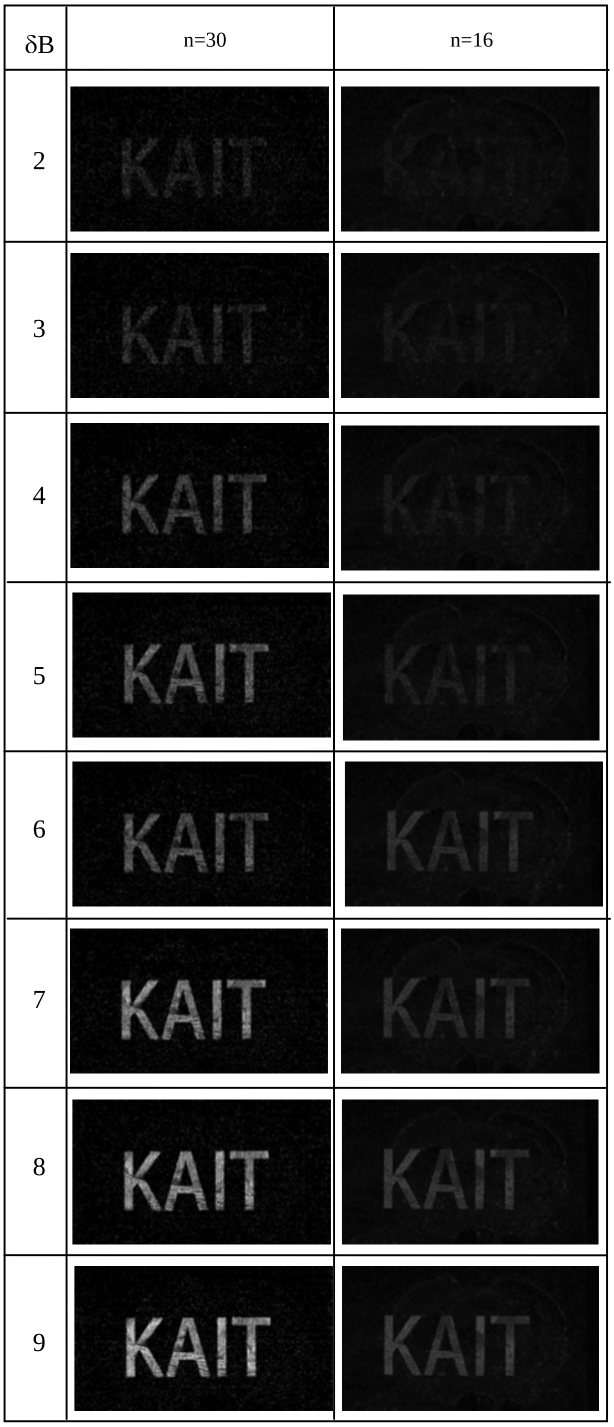

Fig. 9. Example of summed up images modulated by δB.

Figure 9 shows the results we obtained from the summed up images. The frame number, *n*, used for summing up was thirty for images in the left column, and sixteen for those in the right column. Parameter δB was changed from two to nine. The contrast of the summed up image increased gradually with δB. The contrast in the summed up image was greater when *n* equaled 30 than when n equaled 16. Figure 9 shows that the readout pattern can clearly be seen for a δB of four or more when the number of summed-up frames is 30. When the number of summed up frames is 16, the readout pattern can clearly be seen for a δB of 8.

These results indicate a hidden pattern can be read out with sufficient readability by using a δB of four or more and 30 summed up frame images.

IV. CONCLUSION

We proposed a new display technique that can hide the information in a displayed image. It uses a temporal modulated invisible pattern for moving images and when they are read out, the frame images over some periods are summed up to raise the contrast of the invisible pattern so as to make it visible. We also proposed a method that solves the problem of asynchrony between the display and video camera. We conducted experiments and the results obtained from these revealed that hidden binary images could be read out. Moreover, we also confirmed that the patterns used in this technique were invisible. As a result, we demonstrated the feasibility of the technique we propose.

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