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Optically Written Watermarking Technology Using Repeated Block Patterns

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Abstract **-** We propose a new optically written watermarking technology that can enhance the invisibility of watermarking patterns that are projected onto objects. The new method uses repetitive block patterns in which the brightness of pixels where "1" is embedded is slightly higher than that of pixels where "0" is embedded. This difference in brightness is too small to perceive. However, since all the blocks have the same pattern, embedded data based on this difference can be abstracted from the captured image of an object by summing up the data of pixels at the same coordinates in a block for all blocks. We conducted simulations and the results from these revealed that embedded data could be read out extremely accurately at 100%. Moreover, we also confirmed that the patterns used in this technique were invisible even when viewed at a distance of 50 cm. As a result, we demonstrated the practical feasibility of the technology we propose.

Keywords**:** Optical watermarking, Portrait rights, Invisible pattern, Authentication, Content protection, Image processing.

1. Introduction

The importance of techniques of digital watermarking has recently been raised ((M.D. Swanson et al, 1998), (M. Hartung et al, 1999)). However, conventional techniques of digital watermarking rest on the premise that the distributors of content who want to protect their copyrights can embed watermarking. However, there are some cases where this premise does not apply. One such case can arise for printed images that have not been produced from digital data, e.g., art works at museums that have been painted by artists. The images produced by capturing these paintings with digital cameras have been vulnerable to illegal use since they have not contained digital watermarking.

We have proposed a technology that can prevent the use of images of objects in such cases (Uehira and Suzuki, 2008). It uses illumination that contains invisible information on watermarking. As the illumination contains the watermarking, the photographs of objects that are illuminated by such illumination also contain watermarking. Watermarking information can be extracted in the same way as that with the conventional watermarking technique by digitalizing these photographic images.

We used an orthogonal transform to produce and read out watermarking. The watermarking area consisted of numerous blocks, which were blocks of 8x8 pixels (Ishikawa et al, 2011) or lines of one pixel width (Komori and Uehira, 2013). The 1-bit binary data for watermarking were expressed using the sign of a high-frequency component produced by the orthogonal transform. High-frequency patterns should be invisible. However, they can be perceived when we look at them closely or magnify them because the contrast of high frequency patterns has to be high to enhance accuracy in reading the sign of high-frequency components of the patterns.

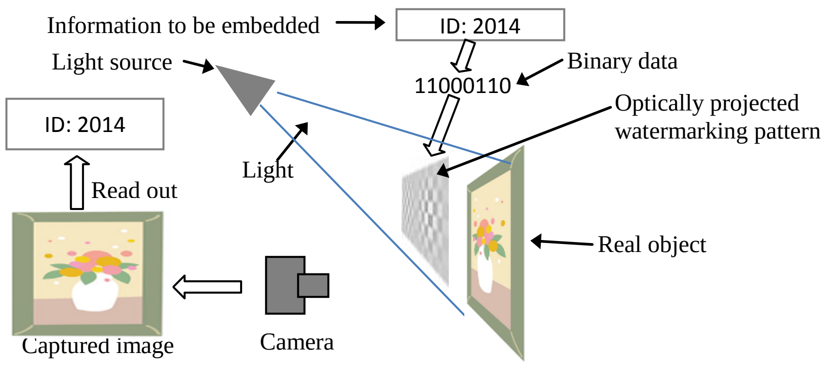

Fig. 1. Basic concept underlying technology of watermarking that uses light to embed data.

This paper presents a new technique of optical watermarking that enables the patterns of watermarking to be made even more invisible using repetitive block patterns. It also describes simulations we conducted to evaluate the proposed technique.

2. Optical Watermarking and Technique Using Repetitive Block Patterns

Figure 1 outlines the basic concept underlying the technology of optical watermarking that uses light to embed data. An object is illuminated by light that contains invisible information on watermarking. As the illumination contains the watermarking information, the photograph of an object that is illuminated by such illumination also contains watermarking. Watermarking information can be extracted in the same way as that with the conventional watermarking technique by digitalizing this photographic image. The light source used in this technology provides a 2D-illumination distribution like that with a projector. The watermarking information is expressed in the form of this 2D-illumination distribution; however, the spatial change in illumination has to be imperceptible to the human-visual system. We used high-frequency patterns to achieve this. However, they can be perceived when the contrast of the patterns is high and we magnify them or look at them closely.

Figure 2 outlines the basic concepts of the new technique we propose in this study that uses repetitive block patterns. The pattern projected onto a real object consists of numerous blocks similarly to that in our previous study (Fig. 2 (a)). However, all the blocks had the same pattern in this study. The 1-bit

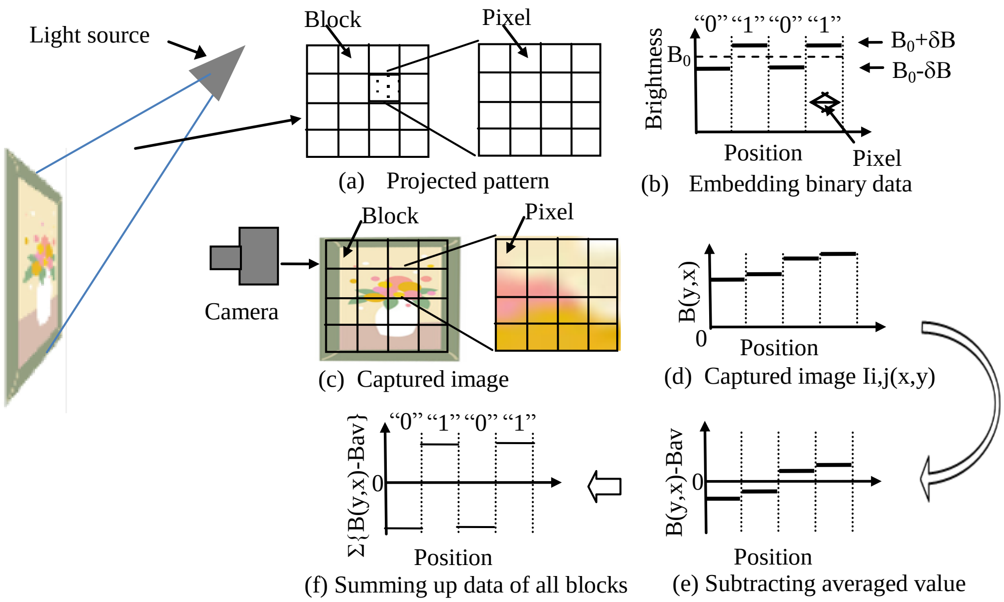

Fig. 2. Basic concepts of new technique using repetitive projected block pattern.

binary data were embedded in each pixel in the block. Fig. 2 (b) illustrates how the data were embedded. The graph in Fig. 2 (b) indicates one direction for simplicity and one division on the horizontal axis indicates a pixel. We set the standard brightness, B_0, of the pattern and when we embedded “1” in the pixels, we increased the brightness of the pixels by δB and when we embedded “0” in the pixels, we decreased it by δB, i.e., the pixel brightness was B_0-δB when “0” was embedded and it was B_0+δB when “1” was embedded. Since δB is very small, the difference between these two kinds of pixels could not be perceived.

Figs. 2(d)–(f) and Eqs. 1 and 2 show how the embedded data were abstracted from the captured image. Captured image $I_{i,j}(x,y)$ is expressed by the product of reflectance of object surface Ri,j(x,y) and the brightness of projected pattern B(x,y). Here, i and j indicate the coordinates of the block and x and y indicate the coordinates of the pixels in the block. We used the difference between the brightness of pixels and the averaged brightness of all the pixels in the block in the captured image as shown in Fig. 2 (f) to abstract the embedded data. These differences between pixels that were in the same position in each block were summed up. This summation $I_S(x,y)$ is given as:

$$I_S(x,y)$$
$$= \sum_{i,j}\{I_{i,j}(x,y) - I_{av}\} = \sum_{i,j}\{R_{i,j}(x,y)\,B(x,y) - I_{av}\} = \sum_{i,j}[R_{i,j}(x,y)\,\{B_0(x,y) \pm \delta B\} - I_{av}]$$

$$= \sum_{i,j}\{R_{i,j}(x,y)\,B_0(x,y) - I_{av}\} \pm \sum_{i,j} R_{i,j}(x,y)\,\delta\text{B} \quad \text{and} \qquad (1)$$

$$= \pm \sum_{i,j} R_{i,j}(x,y)\,\delta B. \qquad (2)$$

The first term at the right in Eq. 1 becomes zero when there are many blocks because these values are distributed around the value of I_{av}. However, the second term increases by summing up because the signs of the values of all the summed up pixels are the same depending on whether “1” or “0” is embedded in the pixels at the coordinates (x and y) of the block. Therefore, we can determine whether the embedded data are “1” or “0” by checking the sign in Eq. 2.

3. Simulations

We carried out simulations to demonstrate the feasibility of the technology we propose. A captured image could be simulated by calculating the product of reflectance of an object and intensity of illumination on the object for every pixel of the captured image. We used the two images in Fig. 3 as objects. The intensity of illumination was that of a pattern image for projecting onto the objects. We chose 2560 (V) x 2048 (H), 1280 (V) x 1024 (H), and 640 (V) x 512 (H) pixels for the captured images in the simulations. The projected images had the same number of pixels as the captured images. Each block in the projected images had 16 x 16 pixels; therefore, the number of blocks changed depending on the number of pixels in the projected images. We set the standard value of brightness in the pattern image to 200 and δB in Eqs. 1 and 2 was changed from 1 to 10 as an experimental parameter. We embedded 512 data in the projected image since there were 16 x 16 pixels in a block and R-and B-component images

Image A


Image B


Fig. 3. Images used as objects.

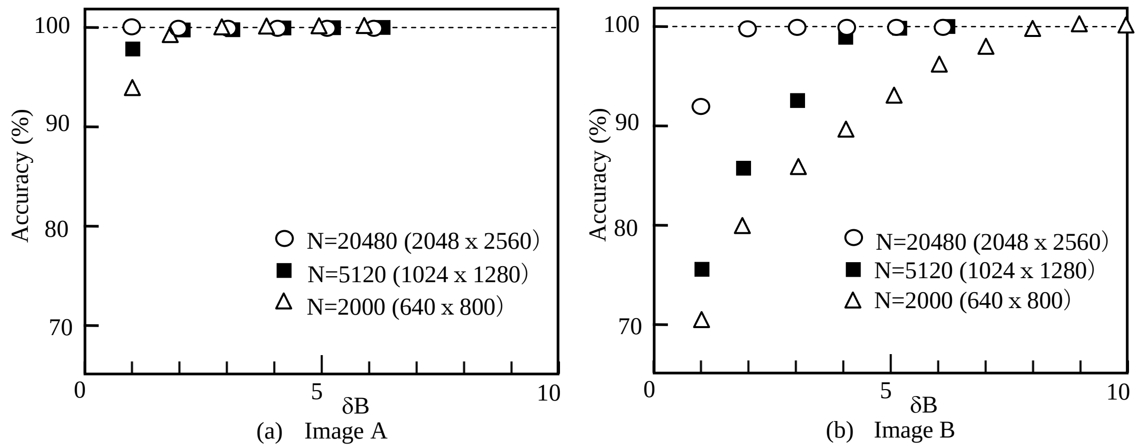

Fig. 4. Experimental results on accuracy with which embedded data were read out. N indicates number of blocks used for summation.

were used to embed the data. The numbers of "1" and "0" data were the same and they were embedded in random pixel positions. Then, data on pixels were summed up for all blocks to read out embedded data using Eq. 2, and how accurately the embedded data were read out was evaluated.

4. Results and Discussion

Fig. 4 plots the simulation results for the accuracy with which the embedded data were read out. The N in the figure indicates the number of blocks and the numbers in parentheses indicate how many pixels were in the captured images. Accuracy is indicated by the percentage of data that were read out correctly from the entire amount of data. It can be seen from Fig. 4 that accuracy increased as δB or the number of blocks used in the summation increased and the embedded data could be read out with 100% accuracy when δB was over nine under all conditions. It was possible to obtain 100% accuracy when δB was over four for captured images whose size was over 1024 x 1280, and over 2024 x 2560 when δB was over two.

The main reason that accuracy for Image B was less than that for Image B was that Image B had a yellow region in the body of the ship and reflectance in the B-component of that region was very low and almost zero. Therefore, the addition of δB in Eq. (2) made little contribution to the results.

Four observers confirmed that the pattern projected onto the objects could not be seen in the captured images for δB of three or less when they were displayed on a 21-inch LCD and viewed at a distance of 50 cm although those used in the previous study could be perceived under these conditions. Therefore, it can be seen from Fig. 4 that we can satisfy both invisibility and readability of embedded data by using over 20000 blocks.

5. Conclusion

We proposed a new optical watermarking technology that used repetitive block patterns to enhance the invisibility of the watermarking pattern. We conducted simulations to evaluate the feasibility of the technique. The results revealed that embedded data could be read out extremely accurately at 100% and they were invisible using over 20000 repeated patterns. We also confirmed that the patterns used in this technique were more invisible than those in a previous study. As a result, we demonstrated the practical feasibility of the technology we propose.

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