DIGITAL WATERMARKING TECHNIQUE USING BRIGHTNESS-MODULATED LIGHT

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ABSTRACT

We propose a novel technology that can prevent the illegal use of images of objects that do not have watermarking. This technique uses illumination that invisibly contains the watermarking. As the illumination for the object contains watermarking, the image of the object taken by the camera also contains watermarking and this watermarking can be extracted by image processing. We conducted experiments where one-bit binary data were embedded in one block that consisted of 8 x 8 pixels using the phase of the highest frequency component generated by DCT. The experimental results revealed that embedded data could be read out extremely accurately, reaching 100% with the majority method, which used three data embedded in three separated blocks. The experimental results demonstrated the feasibility of the technology we propose.

1. INTRODUCTION

Techniques of digital watermarking have recently been widely used as increasingly more digital-image content is being distributed through the Internet. This is because digital watermarking effectively protects the copyright of digital images that are sent over networks. Various approaches to concealing watermarking in images have been developed [1]-[3]. The basic concept underlying these is to make watermarking invisible to the human-visual system. However, this invisible information can be made apparent to the human eye or readable by computer after some image processing is done.

Digital watermarking has recently also been used in printed images, where digital watermarking is embedded in the digital data before it is printed [4],[5]. This is to prevent illegal use of images copied by digital cameras or scanners. However, printed images that have not been produced from digital data, i.e., pictures at museums that have been painted by artists, do not contain digital watermarking and images taken of these with cameras can easily be utilized without copyright.

This paper proposes a novel technology that can prevent the use of images of objects that do not have watermarking. The technique we propose uses illumination that contains invisible information on watermarking. As the illumination contains the watermarking information, the image of a photograph of an object that is illuminated by such illumination also contains watermarking. By digitalizing this photographic image, watermarking information can be extracted through various processes in the same way as the conventional watermarking technique. This paper also describes experiments and presents results that demonstrate the feasibility of the technology we propose.

2. PROPOSED DIGITAL WATERMARKING WRITTEN BY ILLUMINATION

Figure 1 outlines the basic concept underlying the technology we propose. An object is illuminated by light that contains the watermarking information. The light source

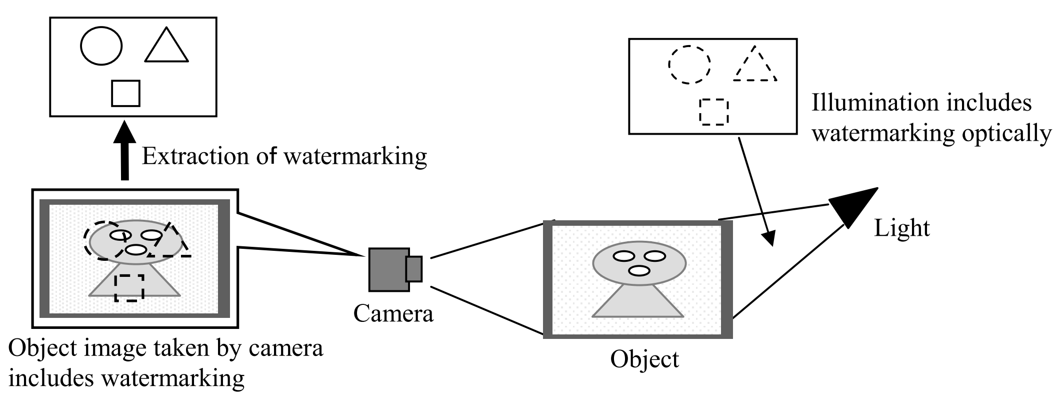

Fig. 1 Basic concept underlying proposed technology

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. The brightness distribution given by this light source then looks uniform to the observer over the object, the same as that with conventional illumination. The brightness of the object surface is proportional to the product of the reflectance of the surface and illumination of the incident light. Therefore, when a photograph of this object is taken, the image on the photograph contains the watermarking information although it cannot be seen. This watermarking can then be identified using image processing.

The main feature of the technology we propose is that the watermarking can be added by light. Therefore, this technology can be applied to objects that cannot be electronically embedded with watermarking, such as pictures painted by artists. Moreover, it has the possibility of being applied to not only flat or 2D objects like pictures but also 3D objects, such as sculptures, merchandise, and the human body. After the watermark is embedded in the object image, the same method as for conventional digital watermarking can be used to identify the watermarking from the object image.

3. METHOD OF PRODUCING WATERMARKS

There are numerous methods of producing watermarks based on the concept we discussed in Section 2; however, in this study, we used the Discrete Cosine Transform (DCT) to produce the watermarking. Figure 2 illustrates the procedure for watermarking, which is similar to the conventional watermarking technology that is electrically embedded. The watermarking area consists of numerous blocks and each consists of 16x16 or 8x8 pixels. All blocks have a DC component. This gives an average brightness for the entire watermarking area, i.e., brightness of illumination. Every block also has the highest-frequency component (HC) in both x and y directions to express the 1-bit binary information for watermarking. We used the phase of the highest-frequency component to express binary data, i.e., “0” or “1”. If the sign of the highest-frequency component in a block was positive, we assumed it expressed “1”, and if the phase was opposite to this (minus), we assumed it expressed “0”.

The watermarking image is expressed mathematically using Eq. (1), which is for 2D inverse DCT (i-DCT).

$$f_{i,j}(x,y) = \sum_{u}^{N-1}\sum_{v}^{N-1} C(u)C(v)F_{i,j}(u,v)\cos\left\{\frac{(2x+1)u\pi}{2N}\right\}\cos\left\{\frac{(2y+1)v\pi}{2N}\right\} \quad (1)$$

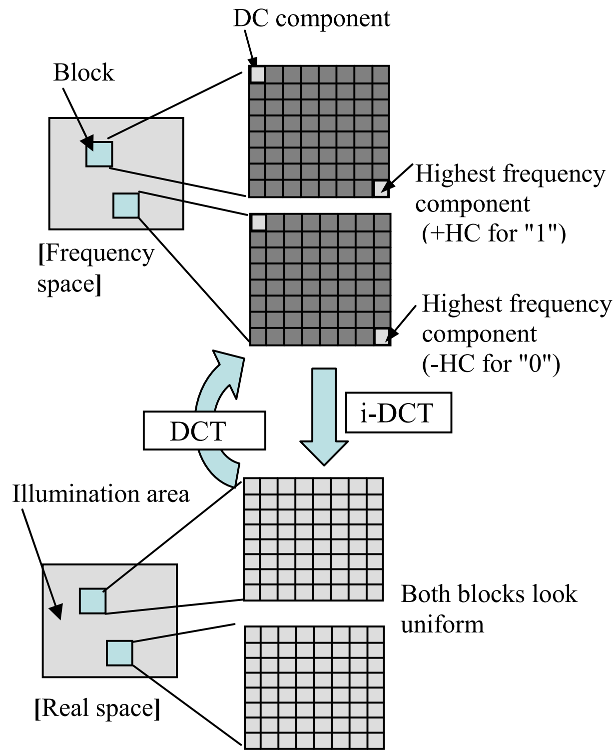

Fig. 2 Watermarking procedure

where $f_{i,j}(x,y)$ is the watermarking image data for pixel (x, y) of the block (i, j), $F_{i,j}(u,v)$ are the data for pixel (u, v) of block (i, j) in frequency space, N is the number of pixels of the block in the x and y directions. C(u), C(v) are given as

$$C(u) = \begin{cases} 1, & u = 0 \\ \sqrt{2}, & u \neq 0 \end{cases} \quad C(v) = \begin{cases} 1, & v = 0 \\ \sqrt{2}, & v \neq 0 \end{cases}$$

$F_{i,j}(u,v)$ is given as

$$F_{i,j}(0,0) = DC \quad (2)$$

$$F_{i,j}(N-1,N-1) = \begin{cases} HC, & \text{if binary data to be embedded in block(i, j) is "1"} \\ -HC, & \text{if binary data to be embedded in block(i, j) is "0"} \end{cases} \quad (3)$$

$$F_{i,j}(u,v) = 0 \ \ (\text{for } u,v \neq 0, N-1) \quad (4)$$

The produced image was projected onto the object using a projector. Because this information for watermarking was expressed using the highest-frequency component, it could not be seen by the human-visual system and it could also be easily read out from object images after it was embedded because the frequency components of the object image were lower than the highest frequency.

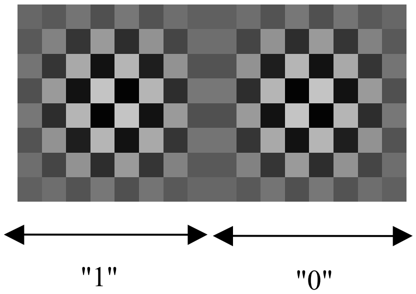

Fig. 3 Part of magnified image of watermarking with two blocks adjoining each other. Contrast of image has been enhanced to reveal pattern.

(a) Image B (b) Image F

Fig. 4 Images used in experiment

Fig. 5 Photograph on which image of watermarking was projected.

4. EXPERIMENTS

We carried out experiments to demonstrate the feasibility of the technology we propose. The key to its feasibility is whether watermarking can be recognized after it is mixed with the digital data of the object image satisfying the condition that it be sufficiently small to be invisible when exposed to light.

We produced watermarking images that consisted of 16 x 16 blocks in this experiment. Each block had 8 x 8 pixels, i.e., the watermarking images had 128 x 128 pixels. Figure 3 shows part of a magnified image of watermarking. The contrast in this image was enhanced so that the pattern could easily be seen.

We used a Digital Light Processing (DLP) projector that had 800 x 600 pixels as a light source. Before the watermarking images were projected, they were enlarged to 256 x 256 pixels to prevent the highest-frequency component from vanishing or decreasing due to pixel data being resampled in the projector. Figure 4 shows the images we used in the experiment as the objects. They were printed images of A4 size. Watermarking images were projected onto these pictures. We also projected them onto a white piece of paper for reference. The area of the projected watermarking image was 15 cm x 15 cm. Figure 5 shows a projected watermarking image on one of the pictures. The values for DC and HC were changed as experimental parameters.

We took a photograph of the projected watermarking image with a digital camera whose resolution was 3888 x 2592 pixels. The projected watermarking area was part of the whole image area taken with the digital camera and the watermarking area had about 500 x 500 pixels. After the photograph was taken, the watermarked area was clipped out as a brighter area than its neighboring by the illumination. It was clipped out as a rectangle neglecting the trapezoidal distortion that occurs when it is projected or when it is photographed with a digital camera. We then transformed the resolution so that there were just 256 x 256 pixels in this area.

We divided this area into 16 x 16 blocks each of which had 16 x 16 pixels and carried out DCT for all blocks using the equation below:

$$F_{i,j}(u,v) = \frac{C(u)C(v)}{M \times M} \sum_{x}^{M-1} \sum_{y}^{M-1} f_{i,j}(x,y) \cos\left\{\frac{(2x+1)u\pi}{2M}\right\} \cos\left\{\frac{(2y+1)v\pi}{2M}\right\} \tag{5}$$

where M is the number of pixels in the u and v directions in frequency space, which was 16 in this experiment.

We then checked the sign of the $F_{i,j}(7,7)$ component for all blocks to read out the embedded one-bit binary information.

We evaluated how accurately the embedded data had been read out. We evaluated two methods of embedding the data. The first was where 1-bit data were embedded in one block (simply referred to as the one-block method after this). The second was where the same 1-bit data were embedded in three blocks sufficiently separated from one another. We determined if their readout data were different using majority (simply referred to as the majority method after this). The latter was to improve the accuracy with which the embedded data was read out.

Table 1 Accuracy of reading out embedded data.

Experimental condition. Brightness of projected pattern			Accuracy (%)					
No.	DC*	HC*	White paper		Image B		Image F	
			1 block	Majority	1 block	Majority	1 block	Majority
1	50	5	98.7	100.0	96.0	100.0	100.0	100.0
2	50	10	100.0	100.0	100.0	100.0	100.0	100.0
3	50	25	100.0	100.0	100.0	100.0	100.0	100.0
4	50	35	100.0	100.0	100.0	100.0	100.0	100.0
5	50	50	100.0	100.0	100.0	100.0	100.0	100.0
6	5	3	100.0	100.0	100.0	100.0	84.4	100.0
7	150	40	100.0	100.0	100.0	100.0	100.0	100.0

* DC and HC are indicated in units of candelas.

5. RESULTS AND DISCUSSION

Table 1 lists the accuracy with which the embedded data was read out. The accuracy is indicated by the percentage of data read out correctly from the entire data. There were 256 whole data for the one-block method and 75 for the majority method. The DC and HC are indicated in units of candelas. These values are those when the watermarking images were projected onto the white piece of paper. Therefore, they were smaller than these values when they were projected onto images B or F.

Four observers confirmed that the checkered pattern of watermarking in Fig.3 was not seen when viewed at a distance of 2 m except for the No.5 condition.

We can see from Table 1 that the embedded data can be read out extremely accurately under all conditions. For a couple of small HCs, the accuracy with the one block method did not reach 100%. This is because the HCs reproduced in the image taken with the digital camera were too small to read in a part of the entire image. Moreover, the accuracy was least for image F, when DC was 5. This was because image F was dark at the top and the HCs reproduced in the image taken with the digital camera decreased drastically due to poor reflectivity.

Judging from the fact that the accuracy for images B and F were as high as those for the white piece of paper, it seems that the high frequency components of the object picture did not affect the sign of the highest frequency component of the watermarking image from being read. Although a few data did not reach 100% with the one block method, all data in the majority method were 100%. These results demonstrate the practical feasibility of the technology we propose.

6. CONCLUSION

We proposed a new technology that can prevent the illegal use of images of objects that do not have watermarking. It uses illumination that contains invisible watermarking. We conducted experiments where one-bit binary data were embedded in one block that consisted of 8 x 8 pixels using the highest-frequency component with i-DCT. The experimental results revealed that embedded data could be read out extremely accurately at 100% for 75 data using the majority method. As a result, we demonstrated the practical feasibility of the technology we proposed.

This technique has the possibility of being applied to 3-D objects, which we intend to do in future work.

7. REFERENCES

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