Illumination Watermarking Technique Using Orthogonal Transforms

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***Abstract*—We propose the "Illumination Watermarking" technology with which the images of objects with no copyright protection can contain invisible digital watermarking, using spatially modulated illumination. This technology can be applied to objects without electronically embedded watermarking such as pictures painted by artists. 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(Discrete Cosine Transform) and WHT(Walsh-Hadamard Transform). The experimental results revealed that embedded data could be read out with almost 100% accuracy in both cases.**

Keywords—Digital watermarking, Illuminated digital watermarking, Spatially modulated illumination, DCT, Illegal photographing protection

1. INTRODUCTION

Techniques of digital watermarking have recently been widely used as increasingly more digital-image content is being distributed through the Internet [1]-[3]. Also, when images are printed, 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, this method can not protect non-digital images like pictures at museums that have been painted by artists, from being illegally captured with digital cameras.

We have proposed a novel technology that can prevent the illegal use of images of objects that do not have watermarking [6]. 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 can be extracted by image processing. We used a Walsh-Hadamard Transform (WHT) as well as a Discrete Cosine Transform (DCT) as methods of embedding the watermarking. This paper describes experiments and presents results that demonstrate the feasibility of the technology we have proposed.

2. PROPOSED DIGITAL WATERMARKING IMPARTED BY ILLUMINATION

Fig.1 outlines the basic concept underlying the technology we have proposed. An object is illuminated by light that contains the watermarking information. The light source used in this technology provides a distribution of 2D-illumination like that possible with a projector. The brightness of the object's surface is proportional to the product of the reflectance of the surface and illumination by the incident light. Therefore, this technology can be applied to objects such as pictures painted by artists without having to use electronically embedded watermarking. Moreover, it also offers the possibility of being applied not only to flat or 2D objects but also 3D objects.

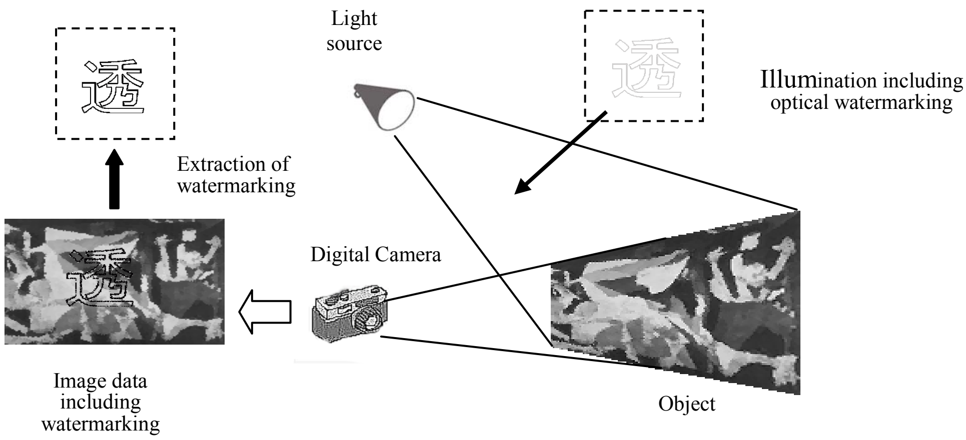

Figure 1. Basic concept underlying proposed technology

3. METHOD OF PRODUCING WATERMARKS AND EXPERIMENTS

Fig. 2 illustrates the procedure for watermarking. The watermarking area consists of numerous blocks and each consists of 16×16 or 8×8 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 HC 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 with Eq. (1), which is for 2D inverse DCT (i-DCT).

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

where $f_{i,j}(x,y)$ are the watermarking image data for pixel (x,y) of block (i,j), $F_{i,j}(u,v)$ are the data for pixe1 (u,v) of block (i,j) in frequency space, and N is the number of pixels in the block in the x and y directions. Here, $C(u)$ and $C(v)$ are given as

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

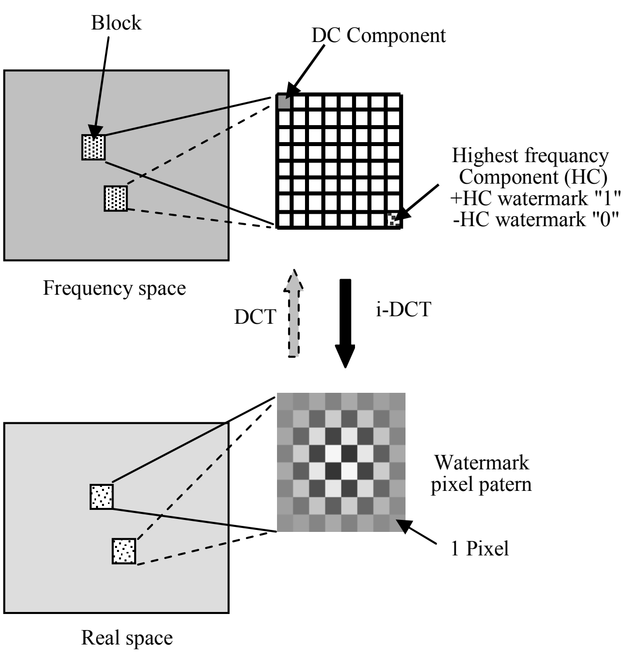

Figure. 2 Watermarking procedure

The other method we used is inverse WHT (i-WHT), which is expressed by Eq. (2),

$$f_{i,j}(x,y) = \frac{1}{N}\sum_{u}^{N-1}\sum_{v}^{N-1} F_{i,j}(u,v)wh(x,u)wh(v,y) \quad (2)$$

where $wh(i,j)$ denotes a component of the Walsh-Hadamard matrix in Table 1(a).

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

$$F_{i,j}(0,0) = \text{DC} \quad (3)$$

$$F_{i,j}(N-1,N-1) = \begin{cases} \text{HC, if binary data to be embedded in block } (i,j) \text{ are "1"} \\ \text{-HC, if binary data to be embedded in block } (i,j) \text{ are "0"} \end{cases} \quad (4)$$

$$F_{i,j}(u,v) = 0 \ (\text{ for } u,v \neq 0, \text{ N-1}) \quad (5)$$

Table 1. Walsh-Hadamard Matrix

(a) 8×8 Matrix

1	1	1	1	1	1	1	1
1	1	1	1	−1	−1	−1	−1
1	1	−1	−1	−1	−1	1	1
1	1	−1	−1	1	1	−1	−1
1	−1	−1	1	1	−1	−1	1
1	−1	−1	1	−1	1	1	−1
1	−1	1	−1	−1	1	−1	1
1	−1	1	−1	1	−1	1	−1

(b) 16×16 Matrix

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	−1	−1	−1	−1	−1	−1	−1	−1
1	1	1	1	−1	−1	−1	−1	−1	−1	−1	−1	1	1	1	1
1	1	1	1	−1	−1	−1	−1	1	1	1	1	−1	−1	−1	−1
1	1	−1	−1	−1	−1	1	1	1	1	−1	−1	−1	−1	1	1
1	1	−1	−1	−1	−1	1	1	−1	−1	1	1	1	1	−1	−1
1	1	−1	−1	1	1	−1	−1	−1	−1	1	1	−1	−1	1	1
1	1	−1	−1	1	1	−1	−1	1	1	−1	−1	1	1	−1	−1
1	−1	−1	1	1	−1	−1	1	1	−1	−1	1	1	−1	−1	1
1	−1	−1	1	1	−1	−1	1	−1	1	1	−1	−1	1	1	−1
1	−1	−1	1	−1	1	1	−1	−1	1	1	−1	1	−1	−1	1
1	−1	−1	1	−1	1	1	−1	1	−1	−1	1	−1	1	1	−1
1	−1	1	−1	−1	1	−1	1	1	−1	1	−1	−1	1	−1	1
1	−1	1	−1	−1	1	−1	1	−1	1	−1	1	1	−1	1	−1
1	−1	1	−1	1	−1	1	−1	−1	1	−1	1	−1	1	−1	1
1	−1	1	−1	1	−1	1	−1	1	−1	1	−1	1	−1	1	−1

SCID N2

SCI D N5

SCID N6

Figure 3. Images used in experiment

We produced watermarking images that consisted of 16 × 16 blocks in this experiment. Each block had 8 × 8 pixels, i.e., the watermarking images had 128 × 128 pixels.

We used a Digital Light Processing (DLP) projector that had 800 × 600 pixels as a light source. Fig. 3 shows the images we used in the experiment as the objects. They were printed A4 images. A white piece of paper was also used for reference. The area of the projected watermarking image was 105 × 105mm on the object image, which was about 650 × 650 pixels taken with a digital camera with a resolution of 4288 × 2848 pixels. The values for DC and HC were changed as experimental parameters. The photographed watermarking area was clipped out as an area that was brighter than its neighbors due to the illumination. A rectangle was clipped out neglecting the trapezoidal distortion that occurs when it is projected or when it is photographed with a digital camera. The resolution of the clipped area was then transformed to just 256 × 256 pixels, and divided into 16 × 16 blocks each of which had 16 × 16 pixels and we carried out DCT for all blocks using Eq. (6),

$$F_{i,j}(u,v) = \frac{C(u)C(v)}{M \times M} \sum_{x}^{M-1} \sum_{y}^{M-1} f_{i,j}(x,y) \cos\{\frac{(2x+1)u\pi}{2M}\} \cos\{\frac{(2y+1)v\pi}{2M}\} \tag{6}$$

We also utilized Eq. (7) for WHT, using the values in Table 1(b) as the components of matrix $wh(i,j)$.

$$F_{i,j}(u,v) = \frac{1}{M} \sum_{x}^{M-1} \sum_{y}^{M-1} f_{i,j}(x,y) wh(u,x) wh(y,v) \tag{7}$$

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

The accuracy with which the embedded data were read out was evaluated by checking the sign of the $F_{i,j}(7,7)$ components for all blocks. We evaluated two methods of embedding the data. The first was the one-block method where 1-bit data were embedded in one block. The second was the majority method where the same 1-bit data were embedded in three blocks sufficiently separated from one another, and we determined if their readout data were different using a majority decision. The latter was to improve the accuracy with which the embedded data was read out.

4. RESULTS AND DISCUSSION

Figs.4 (a)-(d) show how accurately the embedded data were read out. There were 256 whole data for the one-block method and 75 for the majority method. The DC value was fixed at 150, which was measured to be about 90.0 cd/m^2 when the watermarking images were projected onto the white piece of paper. We can see from Fig. 4 that the accuracy with the one-block method was 100% at HC=7 and over, and the accuracy with the majority method was 100% at HC=5 and over. We can see no apparent differences between DCT and WHT. Objective evaluation was also done by four observers using a printed image of the watermarking pattern projected onto the white piece of paper, when viewed for 2 or 3 s from a distance of 50 cm. Three out of four observers stated that the watermarking pattern could not be recognized under the conditions of HC=5.

As a result of these experiments, DCT and WHT were not distinctly different in terms of the efficiency of watermarking. From the point of view of implementation, WHT costs much less and has higher processing speed than DCT. However, as recent microprocessor technology has provided strong functionality for multimedia data processing, DCT is also sufficiently feasible for the illumination watermarking technology we propose.

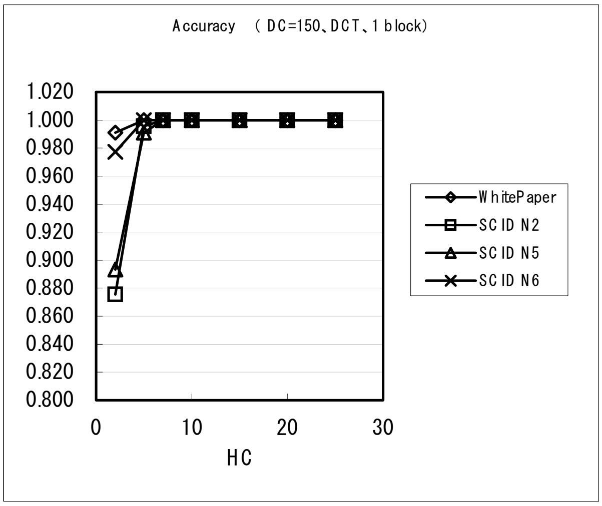

Figure 4. (a) Accuracy of reading out data : DCT (1 block evaluation)

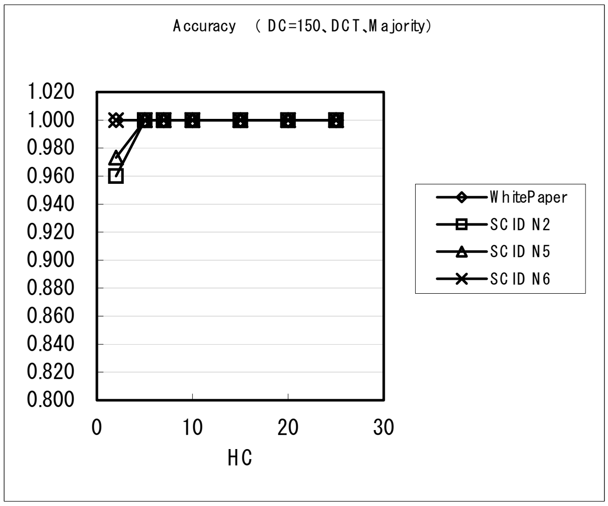

Figure 4. (b) Accuracy of reading out data : DCT (Majority of 3-block evaluation)

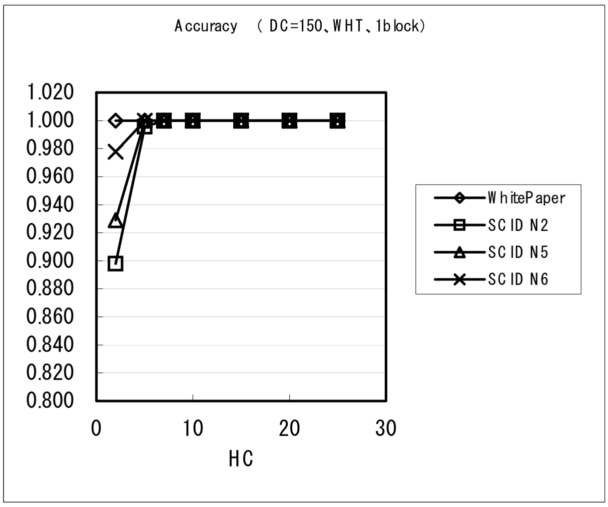

Figure 4. (c) Accuracy of reading out data : WHT (1 block evaluation)

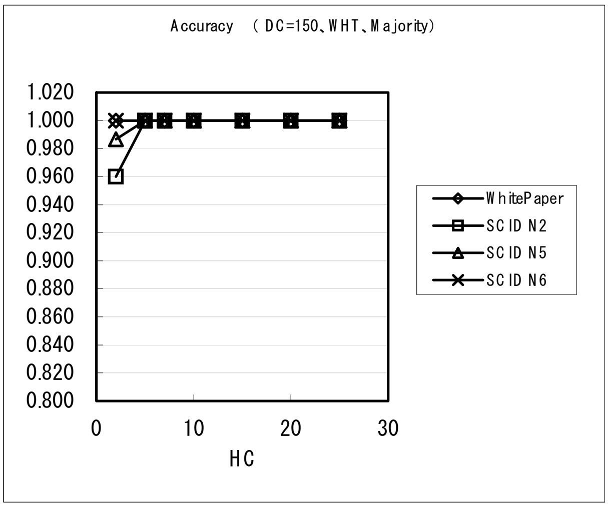

Figure 4. (d) Accuracy of reading out data : WHT (Majority of 3-block evaluation)

5.CONCLUSION

This paper proposed a new method that can prevent the illegal use of images of objects that do not have watermarking. lt uses illumination that contains invisible watermarking. We conducted experiments where one-bit binary data were embedded in one block that consisted of 8 × 8 pixels using the highest-frequency component with i-DCT and i-WHT. 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 propose. This result seems to suggest that not only i-DCT and i-WHT but also various orthogonal transforms can be used for embedding watermarks into illuminations. The verification of this hypothesis is an issue to be studied in the future.

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