Robust Optical Watermarking Technique by Optimizing the Size of Pixel Blocks of Orthogonal Transform

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***Abstract* -- We previously proposed a novel technology with which the images of real objects with no copyright protection could contain invisible digital watermarking, using spatially modulated illumination. In this "optical watermarking" technology we used orthogonal transforms such as a Discrete Cosine Transform (DCT) or a Walsh-Hadamard Transform (WHT) to produce watermarking images, where 1-bit binary information was embedded into each pixel block. Here, we propose a new robust technique of optical watermarking that varies the size of pixel blocks by a trade-off in the efficiency of embedded watermarking. We conducted experiments where 4x4, 8x8, and 16x16 pixels were used in one block. A detection accuracy of 100% was obtained by using a block with 16x16 pixels when embedded watermarking was extremely weak, although the accuracy did not reach 100% by using blocks with 4x4 or 8x8 pixels under the same embedding conditions. The results from experiments revealed the effectiveness of our proposed technique.**

***Index Terms*-- Digital watermarking, Optical watermarking, Spatially modulated illumination, Orthogonal transform, protection against illegal photographing.**

I. INTRODUCTION

As digital image content is increasingly being distributed throughout various media, techniques of digital watermarking have been widely recognized as methods of protecting the copyrights of image content [1]-[3]. For example, digital watermarking is embedded in digital data before it is printed to prevent illegal use of images copied by digital cameras or scanners [4]-[6]. However, digital watermarking with this method has to be embedded before the image content itself is distributed. This cannot prevent photographs of valuable paintings in museums and galleries from being illegally taken with digital cameras.

We previously proposed a novel technology that could prevent the illegal use of images of objects that did not have watermarking [7][8]. This "optical watermarking" technique used illumination that invisibly contained the watermarking. An image of an object irradiated with such illumination also contained watermarking. The watermarking from an image taken with a camera could be extracted by image processing. We used orthogonal transforms such as a Discrete Cosine Transform (DCT) or a Walsh-Hadamard Transform (WHT) as methods of embedding the watermarking. We also previously proposed techniques that were robust to various distortions due to the shooting and reflectance conditions of objects in practical cases [11]. Here, we propose a new technique of robust optical watermarking and describe experiments and present results that demonstrate the feasibility of the new technology.

II. PROCEDURE FOR PRODUCING OPTICAL WATERMARKING

Fig. 1 illustrates the procedure for watermarking using DCT or WHT. The watermarking area is divided into units of $N \times N$ pixel blocks, and each block has a DC component that 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 the x- and y-directions to express the 1-bit binary information for watermarking. We used the phase of HC to express binary

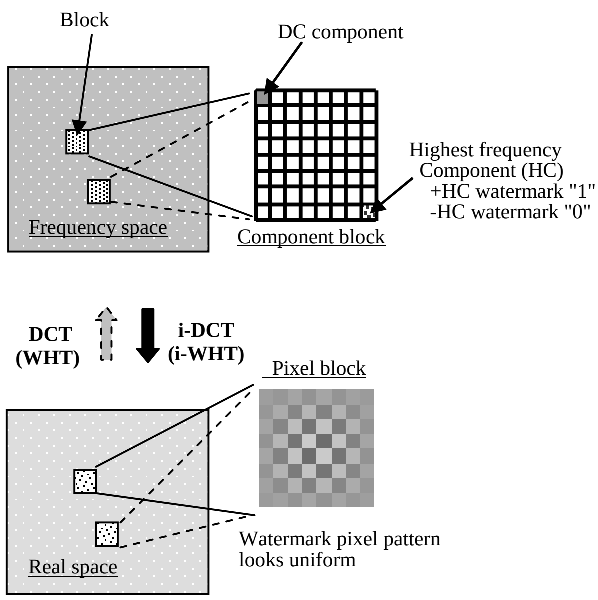

Fig. 1. Producing watermarks using DCT and WHT

Table 1. Walsh-Hadamard matrix

(a) 4×4 matrix

1	1	1	1
1	1	−1	−1
1	−1	−1	1
1	−1	1	−1

(b) 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

(c) 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

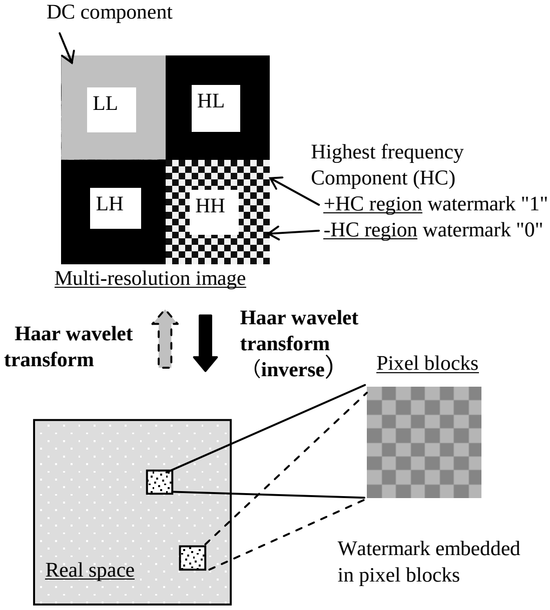

Fig. 2. Producing watermarks using Haar wavelet transform

data i.e., "0" or "1". When a 2D inverse DCT (i-DCT) is used to produce watermarking images, this is mathematically expressed by Eq.(1).

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

where $f_{i,j}(x,y)$ are the watermarking image data for pixel (x,y) of block (i,j) in real space, $F_{i,j}(u,v)$ are the data for component (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

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

When a 2D inverse WHT (i-WHT) is used, the equation is expressed by Eq. (2).

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

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

Fig. 2 illustrates where a Discrete Wavelet Transform (DWT) is used to produce watermarking images, which means that a multi-resolution image is used to express the layer of frequency components. A DC value is given to the whole plane of the LL component image, and this gives an average brightness to the entire watermarking area. The highest frequency component (HC) value for the HH component image is provided to every $\frac{N}{2}\times\frac{N}{2}$ component block, and this yields the 1-bit binary information as watermarking data. The phase of HC is used to express binary data i.e., "0" or "1". All component values for the LH component image and the HL component image are provided to "0". With $\frac{M}{2}\times\frac{M}{2}$ pixels as the size of each component image, a watermarking image of $M\times M$ pixels is produced using a inverse DWT. We used Haar Wavelet Transform (Haar DWT) as the algorithm for the DWT. Fig.3 has details on the Haar DWT. The equations for forward and inverse Haar DWT are in this figure, which are simple linear equations. Watermarking image data generated by Haar DWT become equivalent watermarking image data generated by WHT with the same DC and HC values.

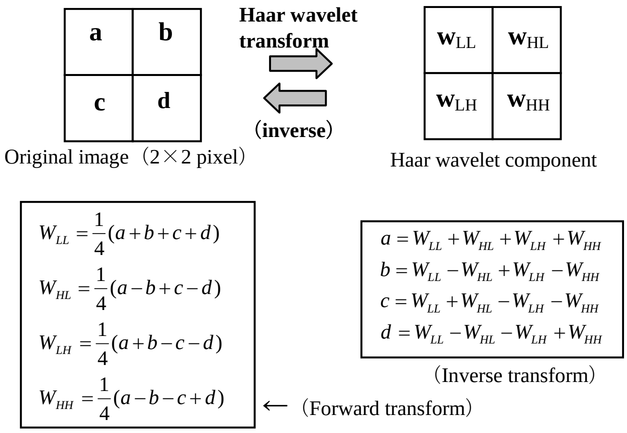

Fig. 3. Haar wavelet transform

III. EXPERIMENTS AND RESULTS

We produced watermarking image data in the experiments that had blocks of 4×4, 8×8, and 16×16 pixels and evaluated the accuracy with which embedded watermarking information could be detected. As the entire watermarking area was 128×128 pixels, the number of blocks in the watermarking area was 32×32 when a block with 4×4 pixels was used, 16×16 when a block with 8×8 pixels was used, and 8×8 when a block with 16×16 pixels was used. The watermarking images made with the procedure explained in the previous section were projected on to pictures as objects with a projector, and the image data including an optical watermark were captured with a digital camera.

A Digital Light Processing (DLP) projector was used as a light source that had a resolution of 800×600 pixels. The objects were printed A4 images of the standard image data. The value for DC was fixed at 150, and the values of HC were varied as these were the experimental parameters. The size of the projected watermarking area was about 105mm× 105mm on the object image, which was about 650×650 pixels taken with a digital camera that had a resolution of 4288×2848 pixels. Figs. 4 (a) - (f) show images of parts of objects embedded with watermarking.

A rectangle was clipped out from the captured image data as a watermarked area that was brighter than its neighbors. The clipped area was then reduced to 128×128 pixels with image processing and was divided into each block of $N \times N$ pixels, and a forward orthogonal transform was carried out on all blocks. When DCT was used, Eq. (3) was used as the forward transform,

$$F_{i,j}(u,v)=\frac{C(u)C(v)}{N\times N}\sum_{x}^{N-1}\sum_{y}^{N-1} f_{i,j}(x,y)\bullet \cos\{\frac{(2x+1)u\pi}{2N}\}\cos\{\frac{(2y+1)v\pi}{2N}\} \quad (3)$$

Here, $C(u)$ and $C(v)$ are the same as those in Eq. (1).

When WHT was used, Eq. (4) was utilized for the forward transform, where the values in Table 1 were used as the components of matrix $wh(i,j)$.

$$F_{i,j}(u,v)=\frac{1}{N}\sum_{x}^{N-1}\sum_{y}^{N-1} f_{i,j}(x,y)wh(u,x)wh(y,v) \quad (4)$$

The accuracy with which the embedded data were read out was evaluated by checking the sign of the $F_{i,j}(N-1,N-1)$ components for all blocks where either DCT or WHT was used.

When Haar DWT was used, the watermarking area that was clipped out was also transformed to 128×128 pixels. As forward Haar DWT was carried out on the entire watermarking area of 128×128 pixels, a multi-resolution image was obtained, and the HH component image was separated from this multi-resolution image. If the embedded watermarking information was correctly read out, a +HC value or -HC value appeared on every $\frac{N}{2}\times\frac{N}{2}$ component block of the HH component image. However, if the spatial-frequency component of the object image contained an HH frequency element, the coefficients in an $\frac{N}{2}\times\frac{N}{2}$ component block may be disrupted by noise derived from this element. We therefore used the procedure in Fig. 5 to read out the embedded watermarking data. First, the mean value of all coefficients of every $\frac{N}{2}\times\frac{N}{2}$ component block in the HH component image was calculated, where 1-bit binary information was embedded, and the mean value was evaluated. If the phase of the mean value we obtained was negative the watermarking data that was read out was "0", and if the phase was positive, it was "1".

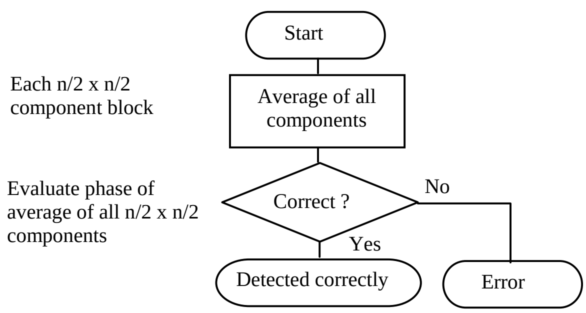

Fig. 5. Procedure for detecting optical watermarking using Harr DWT

Fig. 4. (a) Image with watermarking
Block size : 4×4 pixels, DCT, DC=150, HC=15

Fig. 4. (d) Image with watermarking
Block size : 4×4 pixels, WHT and Haar DWT, DC=150, HC=15

Fig. 4. (b) Image with watermarking
Block size : 8×8 pixels, DCT, DC=150, HC=15

Fig. 4. (e) Image with watermarking
Block size : 8×8 pixels, WHT and Haar DWT, DC=150, HC=15

Fig. 4. (c) Image with watermarking
Block size : 16×16 pixels, DCT, DC=150, HC=15

Fig. 4. (f) Image with watermarking
Block size : 16×16 pixels, WHT and Haar DWT, DC=150, HC=15

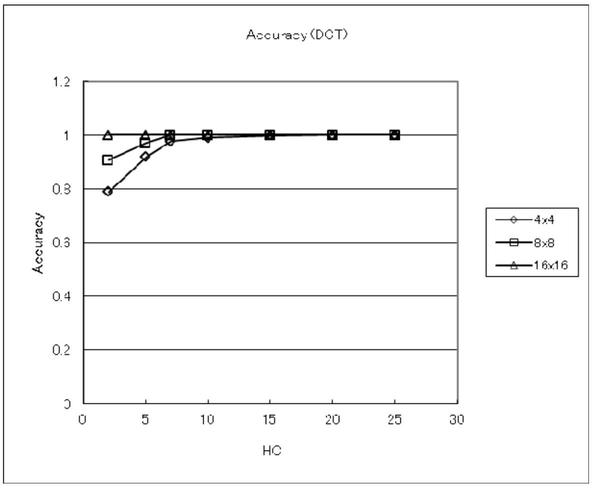

Fig. 6. (a) Accuracy with which data were read out: DCT

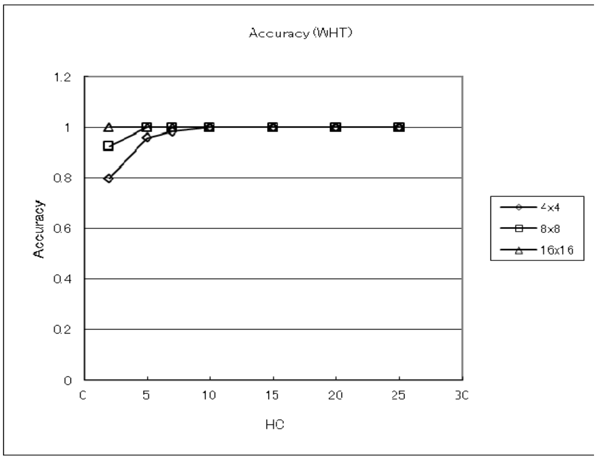

Fig. 6. (b) Accuracy with which data were read out: WHT

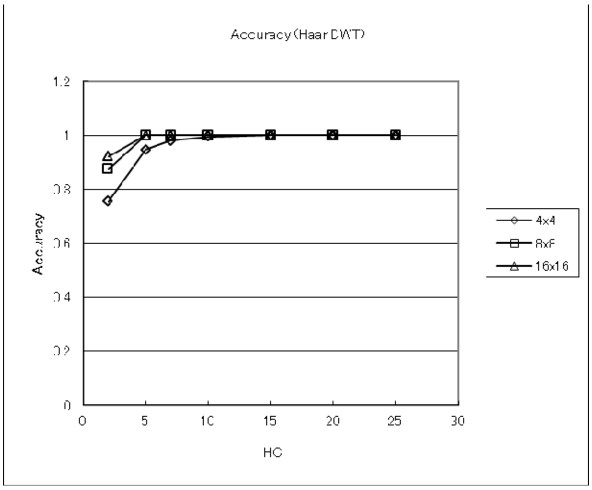

Fig. 6. (c) Accuracy with which data were read out: Haar DWT

Figs. 6 (a) - (c) present the results we obtained from the experiments. When the block of 16×16 pixels was used, a detection accuracy of 100% was obtained using DCT and WHT for all the HC values. In regions of HC=10 and under, the detection rate when a block of 8×8 pixels was used was superior to that when a block of 4×4 pixels was used, when DCT and WHT were employed. Here, WHT demonstrated a slightly more accurate detection rate than DCT. The results when Haar DWT was used indicated that blocks with more pixels had better accuracy in detection. These were the same results as when DCT and WHT were used. However, when HC=2, the accuracy with which data were read out did not reach 100%.

IV. DISCUSSION

We found that blocks with more pixels had a better detection rate from the results of these experiments. When DCT or WHT was used in blocks with 16×16 pixels, a detection accuracy of 100% was obtained with a value of HC=2 that enabled extremely weak embedding. The watermarked image was almost invisible at HC=2.

Because watermarking information is embedded under high frequency elements, if the blocks contain more pixels, embedded information is distributed within a wider area of the object image by optical watermarking, and there is the possibility that interference by a specific part of the object with low reflectivity will be low. As a result, the accuracy with which watermarking information is detected is improved, and can offer a method of optical watermarking with tolerance against interference as high as that of the entire pixel block. However, it is clearly advantageous to have fewer pixels in blocks, and this involves a trade-off in the detection rate and tolerance of watermarking against interference that enables embedding to be optimized.

We evaluated the accuracy of detection with Haar DWT and found it was inferior to that with DCT and WHT. This was due to the following causes. The conversion base for Haar DWT was 2×2 pixels per block, and this was fewer than the number of pixels in the blocks for DCT and WHT in these experiments. There may be a possibility that interference in a particular block with 2×2 pixels can not be avoided, although an algorithm was used that compensated for the entire HH component image. However, DWT has an advantage in that it offers a high degree of freedom in the number of pixels per block, for instance, 6×6 and 10×10 pixels can be in one block.

V. CONCLUSION

We proposed a robust technique of optical watermarking by optimizing the number of pixels per block with an orthogonal transform. The results proved that it was practical and that the accuracy of detection of data embedded with optical watermarking could be improved with more pixels in each block. The experimental results revealed that under conditions of very weak embedded watermarking, the accuracy of detection reached 100%, using a block with 16×16 pixels when DCT and WHT were applied to produce the data for watermarking image. However, the volume of information that could be embedded into data for the watermarking image was lower than when blocks with 4×4 or 8×8 pixels were used. Robustness against various disturbances became a trade-off in optimizing embedded watermarking data.

When Haar DWT was used, the accuracy of detection with a block of 16×16 pixels did not reach 100%. However, as the general features of DWT indicated that the pixel resolution in real space and the spatial-frequency resolution in frequency space were independent, the accuracy of detection could be improved when more pixels were used in a block of the conversion base for DWT. We next intend to evaluate the optimal pixel size in the conversion base to obtain sufficiently accurate detection with DWT.

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