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An Image Watermarking Scheme based on FWHT-DCT

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***Abstract*—Digital image watermarking is frequently used for many purposes, such as image authentication, fingerprinting, copyright protection, and tamper proofing. Imperceptibility and robustness are the watermark requirements of good watermarks. In this paper, we propose the Fast Walsh Hadamard transform (FWHT) combined with the Discrete Cosine Transform (DCT) as a new image watermarking scheme. The FWHT reorders the high-to-low sequence components contained in the signal. This scheme produces high perceptual transparency of the embedded watermark. Experimental results show that the proposed scheme has good visual perception and is robust against attacks.**

Keywords—Digital Image Watermarking; Imperceptibility; Robustness; Discrete Cosine Transform; Fast Walsh Hadamard Transform

I. INTRODUCTION

Image watermarking is the process of adding data or information, i.e. watermark, into a host image and it can be extracted to check for any abuse [1]. Image watermarking can be applied into many areas, such as broadcast monitoring, owner identification, proof of ownership, authentication, fingerprinting, copy control, covert communication, tamper detection, content protection, and copyright protection [2,3].

The image watermarking scheme consists of two processes, that is the watermark embedding and the watermark extraction. Imperceptibility and robustness are the most important requirements in watermarking. Imperceptibility is related to the visual quality of the watermarked image caused by embedding the watermark, while robustness is related to the resilience of the watermark from being extracted even after the watermarked image is altered or damaged [3,4].

Based on the technique uses to embed and detect a watermark, digital watermarking can be classified into either the spatial domain or frequency domain category. In the spatial domain, the watermark can be embedded into the least significant bits of the host image using the least significant bits (LSB) technique. In the frequency domain, the watermark can be embedded by modifying the transform coefficients using many transforms, such as the discrete cosine transform (DCT), the discrete fourier transform (DFT), and the discrete wavelet transform (DWT) [3].

Currently, there are many new schemes that have been developed to improve the watermark. Some of the schemes combine the transforms above with other transforms, such as Haar, Slant, Hartley, and Hadamard. The watermarking technique in the Hadamard domain is popular in the literatures.

Bhatnagar and Raman [5] proposed a robust watermarking scheme with multiresolution Walsh-Hadamard Transform using singular value decomposition (SVD). Li, Wang, Song, and Wen [6] proposed a blind multiple watermarking scheme using Hadamard transform. They have presented that this scheme is invisible and robust against attacks. Saeid and Hossein [7] proposed a blind digital watermark embedded with a proportional number of gray-level watermarks to the estimate of the two first Hadamard AC coefficients. In this paper, we propose the Fast Walsh Hadamard Transform (FWHT) combined with DCT as a digital image watermarking scheme. In this scheme, the FWHT to be applied on the original watermark before it embedded on the DC coefficients of the host image.

To describe our proposed scheme, we divide this paper into several sections. Section II presents the basic principles of the DCT and FWHT. Section III presents the image watermarking scheme based on the proposed FWHT-DCT scheme. Section IV consists of the experimental results of the watermarking performance using the FWHT-DCT scheme. The conclusions are presented in the Section V.

II. THE BASIC PRINCIPLES OF DCT AND FWHT

A. Discrete Cosine Transform (DCT)

The 2-D DCT is defined as [4]:

$$C(u,v) = \alpha(u)\alpha(v)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f(x,y)\cos\left[\frac{\pi(2x+1)u}{2N}\right]\cos\left[\frac{\pi(2y+1)v}{2N}\right]$$
$$\text{for } u,v = 0,1,2,\ldots,N\text{-}1 \quad (1)$$

The inverse transform (IDCT) is defined as:

$$f(x,y) = \alpha(u)\alpha(v)\sum_{u=0}^{N-1}\sum_{v=0}^{N-1} C(u,v)\cos\left[\frac{\pi(2x+1)u}{2N}\right]\cos\left[\frac{\pi(2y+1)v}{2N}\right]$$
$$\text{for } x,y = 0,1,2,\ldots,N\text{-}1 \quad (2)$$

In the DCT-based watermarking scheme, the watermark bits are embedded in each $N\times N$-DCT block of the host image. The IDCT is used to reconstruct the watermarked image after the watermark is embedded into the host image.

B. Fast Walsh Hadamard Transform (FWHT)

Hadamard transform matrix is an orthogonal square matrix which only has 1 and -1 of element value. This transform is also known as Walsh-Hadamard transform. H_1 is the smallest Hadamard matrix, and it is defined as [8,9]:

$$H_1 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{3}$$

The Hadamard matrix H_N of size N is constructed by Kronecker product between H_1 and H_{N-1}, where $N=2^n$, n is an integer number.

$$H_N = H_1 \otimes H_{N-1} = \begin{bmatrix} H_{N-1} & H_{N-1} \\ H_{N-1} & -H_{N-1} \end{bmatrix} \tag{4}$$

Eq. (5) shows an example of 4×4-Hadamard matrix, that is $H_2 = H_1 \otimes H_1$, obtained using Eq. (3) and Eq. (4).

$$H_2 = \frac{1}{2}\left[\begin{array}{cc:cc} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ \hdashline 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{array}\right] \begin{array}{c} \scriptstyle \textit{Sign Changes} \\ 0 \\ 3 \\ 1 \\ 2 \end{array} \tag{5}$$

The number of sign changes along each row of the matrix in Eq. (4) is called the sequency of the row. These rows can be considered to be samples of rectangular waves with a subperiod of *1/N* units. These continuous functions are called Walsh's functions [9]. The Hadamard matrix is an orthogonal matrix and satisfies the following relation:

$$H \bullet H^T = I \tag{6}$$

The H is the Hadamard matrix, H^T is the inverse Hadamard matrix, and I is the unitary matrix. The Hadamard transform can be computed in $N \log N$ operations, using the Fast Walsh Hadamard transform algorithm. Suppose x is a signal vector, X is a spectrum vector, and H is the Hadamard matrix. The Walsh-Hadamard Transform (WHT) and Inverse Walsh-Hadamard Transform (IWHT) are defined as [8]:

$$\left.\begin{array}{r} WHT(x) = X = Hx \\ IWHT(X) = x = HX \end{array}\right\} \tag{7}$$

The WHT and IWHT are the forward and inverse of WHT_h, respectively. The sequency ordered Walsh-Hadamard transform (WHT_w) can be obtained by first carrying out the fast WHT_h and then reordering the components of X [8].

For an example, consider x = [1 2 3 4] is a signal vector of N=2 elements. The WHT matrix for this vector is:

$$H_h = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix} \quad and \quad H_w = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix} \tag{8}$$

The forward transform of x and the inverse of X can be found as:

$$X = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix}\begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix} = \begin{bmatrix} 5 \\ -2 \\ 0 \\ -1 \end{bmatrix}; \; x = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix}\begin{bmatrix} 5 \\ -2 \\ 0 \\ -1 \end{bmatrix} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix} \tag{9}$$

In this example, we have FHWT(x) = [5 -2 0 -1] as a FWH transform of x and IFWHT(X) = [1 2 3 4] = x as an inverse.

III. The Proposed Image Watermarking Scheme

A. Embedding the Watermark

The proposed watermark embedding for the FWHT-DCT scheme is shown in Fig. 1 by the following steps:

Step 1. Take the watermark W with $N \times N$ of size $N=2^m$ (m=1,2,...) and apply the FWHT on the watermark W to get the FWHT coefficient, that is W'=FWHT(W).

Step 2. Generate the two pseudorandom number (PN) sequences k_1 and k_2 using the same seed.

Step 3. Take the original image as the host image I and apply the DCT to each 8×8-block of the original image I to get the DC coefficients.

Step 4. Embed the PN sequences with gain factor α in the DC component X in order as follows:

$$X' = \begin{cases} X + \alpha * k_1, & if\, W > W' \\ X + \alpha * k_2, & otherwise \end{cases} \tag{10}$$

Step 5. Apply the inverse of DCT (IDCT) on DC component X' to reconstruct the watermarked image I'.

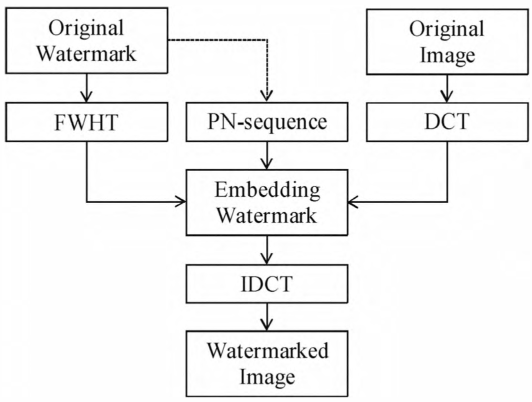

Figure 1. Watermark Embedding Scheme

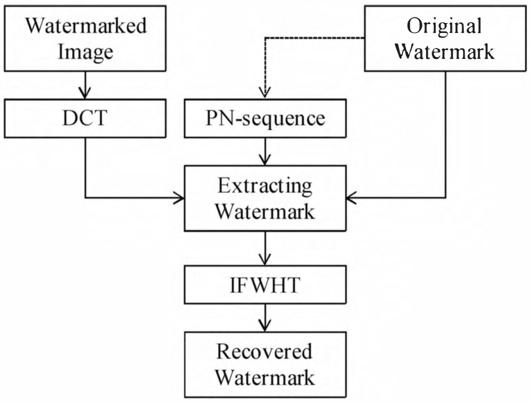

Figure 2. Watermark Extraction Scheme

B. Extracting the Watermark

The watermark extraction scheme is shown in Fig. 2, by the following steps:

Step 1. Apply the DCT to each 8×8-block of the watermarked image.

Step 2. Calculate and compare the correlation coefficient between the DC coefficients *X'* and the two PN sequences k_1 and k_2 to each 8×8-block of watermarked image.

$$W'' = \begin{cases} W', & if\ corr(X',k_1) < corr(X',k_2) \\ W, & otherwise \end{cases} \quad (11)$$

Step 3. Apply the inverse FWHT (IFWHT) on *W''* to reconstruct the recovered watermark.

C. Performance Measurements

In this work, we use the Peak Signal to Noise Ratio (PSNR) and the Normalized Cross Correlation (NCC) measure to analyze the performances of the proposed watermarking scheme. The PSNR, in decibels (dB), is used to evaluate the imperceptibility of the watermarked image [4], and is given by Eq. (12).

$$PSNR = 10.^{10}\log\left[\frac{R^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}[X(i,j)-X'(i,j)]^2}\right] \quad (12)$$

for i=1,2,…,M and j=1,2,…,N

The X is the original image, X' is the watermarked image, R is the maximum fluctuation in the input image data type, M and N are the number of rows and columns in the input images, respectively.

The NCC is used to evaluate the robustness of the watermark, by calculating the correlation (or the similarity) between the original watermark and the recovered watermark [4]. The NCC indicates the similarity between the extracted and the original watermark, and is given by Eq. (13).

$$NCC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[W(i,j)W'(i,j)]}{\sum_{i=1}^{M}\sum_{j=1}^{N}[W(i,j)]^2} \quad (13)$$

for i=1,2,…,M and j=1,2,…,N

The W is the original watermark, W' is the recovered watermark, and M and N are the number of rows and columns in the input images, respectively.

IV. Experimental Results

In our experiments, we use the 'Lena' 512×512 gray scale image as a host image, while the original watermark is the 'Stamp' 64×64 gray scale image as shown in Fig. 3. Due to the characteristics of FWHT, it is necessary to note that this scheme only works on N×N size images. The experiment is performed using Matlab [10,11].

A. Imperceptibilty and Robustness without Attack

Based on the experimental results, the imperceptibility evaluation of the watermarked image gave a PSNR value of 84.89 dB as shown in Fig. 4. Without any attacks, the watermark could be recovered with on NCC value of 0.9993.

B. Imperceptibility and Robustness after Attacks

The imperceptibility and the robustness performance were also measured after they were subjected to interference caused by several attacks. We used several image processing operations as attacks, i.e. noise insertion, JPEG compression, cropping, rotation, and resizing.

Figure 3. Original image and watermark image

PSNR=84.89 dB NCC=0.9993

Figure 4. Watermarked image and recovered watermark without attack

PSNR=58.95 dB NCC=0.9984

Figure 5. Watermarked image and recovered watermark after noise insertion (d=20)

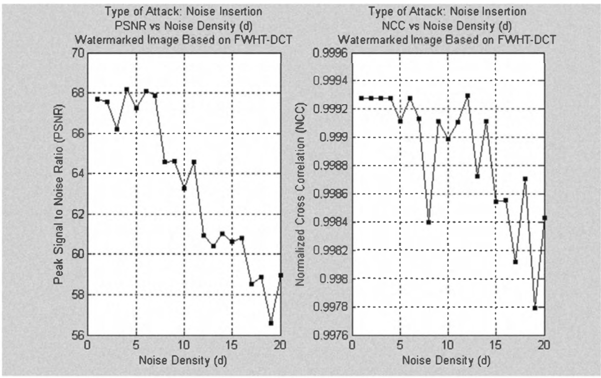

Figure 6. Imperceptibility and robustness after noise insertion

Noise Insertion: The pseudorandom noise signals were inserted into the watermarked image with the noise density d, as given in Eq. (14).

$$X' = X' + d * rand(N) \quad (14)$$

The imperceptibility and robustness after noise insertion using d=20 is shown in Fig. 5. The watermark could be recovered with NCC=0.9984. Increasing the coefficient value of the noise decreases the quality of perceptual invisibility of the watermarked image and also the robustness level of the recovered watermark, as shown in Fig. 6.

JPEG Compression: Experiments with JPEG compression on the watermarked image produced the results in Fig. 7, using the compression quality factor, Q=50. The watermark was be recovered. Unlike the noise insertion, increasing the quality factor of the JPEG compression increased the perceptual invisibility with high PSNR value.

PSNR=84.89 dB NCC=0.9993

Figure 7. Watermarked image and recovered watermark after JPEG Compression (Q=50)

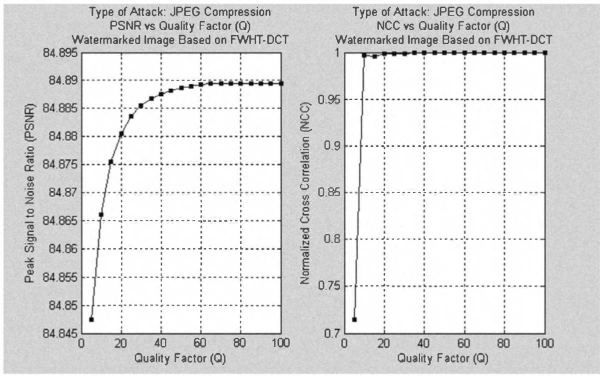

Figure 8. Imperceptibility and robustness after JPEG Compression

This scheme also has good robustness with high values of the compression quality factor. So, the watermark could be recovered with a high NCC, as shown in Fig. 8.

Cropping: In this experiment, a part of the watermarked image is cropped out. The copping area is defined from a certain specific rows and columns of the watermarked image. Experiments with higher values of the cropping area achieved the results as shown in Fig. 9.

The watermark could be recovered in these cases. Fig. 10 illustrates the imperceptibility and robustness after image cropping.

PSNR=84.52 dB NCC=0.9653

Figure 9. Watermarked image and recovered watermark after image cropping (10 rows of cropped area)

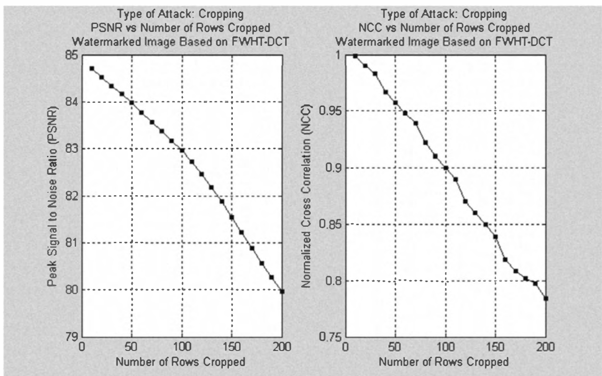

Figure 10. Imperceptibility and robustness after image cropping

PSNR=83.56 dB NCC=0.6624

Figure 11. Watermarked image and recovered watermark after image rotation (*degree*=120°)

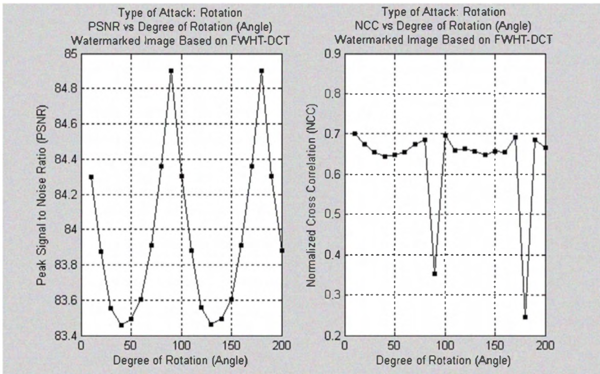

Figure 12. Imperceptibility and robustness after image rotation

Rotation: This experiment was performed by applying a degree of rotation on the watermarked image. The results are shown in Fig. 11. With the 120 degree of rotation, the watermark could be recovered with NCC=0.6624.

As shown in Fig. 12, the imperceptibility level shows a general downward trend when the degree of the image rotation increased. Improvements are noticed at rotations of 90 degree angles (i.e. 90 and 180 degrees).

Resizing: As shown in Fig. 13, the watermark could be recovered with low readability when the image was resized by a factor of image resizing values.

PSNR=84.73 dB NCC=0.7202

Figure 13. Watermarked image and recovered watermark after image resizing (*scale factor*=2x)

Enlarging further produced the results in Fig. 14, where the watermarked image had high perceptual invisibility. The watermark image could be recovered with high NCC values.

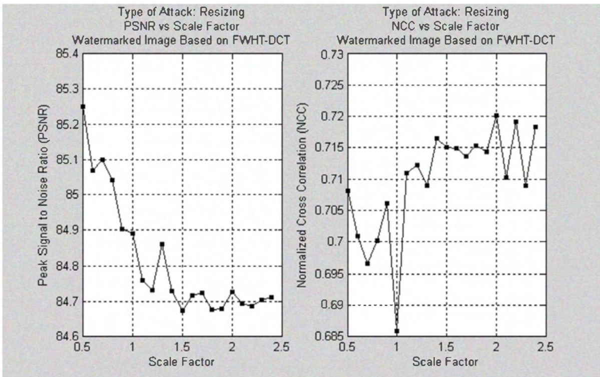

Figure 14. Imperceptibility and robustness after image resizing

V. CONCLUSION

In this paper, we propose the FWHT-DCT as a digital image watermarking scheme. We have presented the evaluation of the watermarking performances in imperceptibility and robustness as the watermarking requirements. The experimental results show that the proposed scheme has a good perceptual invisibility and is also robust against attacks.

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