An Efficient Wavelet-Based Watermarking Algorithm

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Abstract
An efficient digital watermarking technique is proposed for copyright protection. The proposed watermarking algorithm embeds a binary logo watermark by modifying the appropriate subband images in the wavelet domain. The qualified significant wavelet coefficients and their texture and luminance content across two different coarse scales (level 2 and level 3 wavelet decompositions) are utilized to determine the positions and the magnitudes to adaptively embed the digital watermark. The approach can effectively hide a robust watermark due to the exploitation of the characteristics of the human visual system. The correlations between the watermarked wavelet coefficients and the rearranged pseudo-random sequences yielded from the digital logo at these two scales are stored as side information. The watermark is detected by comparing the correlations between the wavelet coefficients and the watermarking code at level 2 and level 3 with the stored side information. The performance of the proposed watermarking is robust to a variety of image processing techniques, such as JPEG compression, sharpening, resizing, and geometric operations.

Keywords
Digital watermark, discrete wavelet transform, qualified wavelet coefficients.

I Introduction

Digital watermark [1, 2] has been prevalently utilized as a possible solution for intellectual property rights protection. It is a technique for labeling multi-media data, including digital images, text documents, video and audio clips, by hiding secret information in the data. This embedded hidden information is unperceivable so the watermarked data appear identical to the original non-watermarked data. Moreover, this hidden information can neither be removed nor decoded without the required secret keys or algorithms.

Any watermarking technique should exhibit at least the following four desirable characteristics:

1) Readability: A watermark should convey as much information as possible so the ownership and copyright can be ambiguously identified.
2) Security: A watermark should be secret and must be undetectable by an unauthorized user in general.
3) Imperceptibility: A watermark should not introduce any perceptible artifacts into the original image.
4) Robustness: A watermark should not be removed after attacks. It should be detected after a variety of distortions, such as JPEG compression and geometric operations.

Several spatial-domain and frequency-domain digital watermarking algorithms have been proposed with different contributions. In general, the frequency-based approaches are better than the spatial-based approaches based on the following observations:

- More bits of watermark can be embedded into the original image;
- More robust to attacks;
- More suitable to model the HVS (Human Visual System) behavior.

Among the proposed frequency-based watermarking approaches, DWT-based (Discrete Wavelet Transform) techniques have gained interest among watermarking researchers. Some methods add pseudo-random sequences to the wavelet domain for watermarking. For example, Cox *et. al.* [3] embed a set of independent Gaussian distributed sequences into the perceptually most significant frequency components of DWT of the images. Wang *et. al.* [4] embed the weighted watermark determined by a subband-dependent value in the most significant DWT coefficients. Barni *et. al.* [5] use a pixel-wise mask to take into account the texture and the luminance content of all image subbands. The watermark is adaptively added to the corresponding largest detail bands determined by the pixel-wise mask without any perceived quality degradation of the image.

Other methods hide binary or gray-scale logos in the wavelet domain for watermarking. Both the binary/gray-scale logo and the original image are hierarchically decomposed by DWT in [6, 7]. In [6], the scaled binary logo is repeatedly added to the DWT decomposition of the image based on the noise sensibility in each small block. In [7], each detail subband of the logo is embedded into the corresponding detail subband of the image based on the variance on a block-by-block basis. Hsieh et. al. [8] adaptively embed the original logo in the qualified significant wavelet trees to achieve the robustness of the watermarking. However, the original image is needed for watermark detection in the last two methods [7, 8].

In this paper, we propose a wavelet-based watermarking approach by adaptively adding a scaled binary logo to the qualified significant wavelet coefficients at the middle frequency bands of the DWT of an image. The proposed watermark considers both the texture and the luminance content modeled from the HVS to ensure no perceivable degradation of the original image. Our experimental results show that the proposed watermarking approach is very robust to image compression and some image distortions.

The remaining sections of this paper are organized as follows:

- Section II describes the watermark embedding approach and the detection method.
- Section III shows the experimental results.
- Section IV draws conclusions.

II. Watermark Embedding and Detection

Since DWT has the excellent spatio-frequency localization property, it has been extensively utilized to identify the image areas where a disturbance can be more easily hidden. In particular, this spatio-frequency localization property effectively exploits the HVS iso- and near-frequency masking effect. We propose to embed digital watermarking (i.e., a binary logo) into the wavelet domain.

We consider the sensitivity of the human eyes when embedding the watermark. These considerations include [9]:

- The eyes are less sensitive to noise in high-resolution bands and in those bands having orientation of 45° (i.e., diagonal direction).
- The eyes are less sensitive to noise in the areas where brightness is high or low.
- The eyes are less sensitive to noise in highly textured areas but, among these, more sensitive near the edges.

The digital watermarking is adaptively embedded in the wavelet domain based on the texture and the luminance content of all subbands so it is invisible to human eyes. Moreover, the watermark is redundantly embedded into the qualified significant wavelet coefficients of subbands of level 2 and level 3 to ensure its robustness upon attacks.

A. Watermark Embedding

The algorithm to embed a watermark in the original image is summarized as follows:

1. Decompose the original image into four levels (thirteen subbands) as shown in Fig. 1.
2. Any binary image with approximately equal number of 0's and 1's is utilized as a watermark image. An example of such watermark image is shown in Fig. 1.
3. Map 0→-1 and 1→ +1 to generate a pseudo-random binary sequence containing either –1 or +1.
4. The subband pairs (LH3, LH2), (HL3, HL2), and (HH3, HH2) at level 3 and level 2 are selected to calculate the changes made in these middle frequency subbands.
   Initialize *TotalChange* as zeros. This *TotalChange* will record the possible changes at each subband pair.
   For each value *A* at (i, j) in the subband LL4 (Approximation subband image)
   - 4.1 /***** Consider both high and low brightness areas *****/
     Let *Brightness* be normalized *A*.
     if (*Brightness* < 0.2) /****** Low brightness areas ******/
     Brightness = 1 – *Brightness* ;
   - 4.2 /***** Consider the highly textured areas including the areas near the edges *****/
     - 4.2.1 Let *Var* be the variance of the 2×2 subblock whose upper-left corner positioned at (i, j) in LL4.
     - 4.2.2 Find the associated three 2×2 and 4×4 subblock pairs at the horizontal, vertical, and diagonal directions of level 3 and level 2 as illustrated in Fig. 1 and Fig. 2.
     - 4.2.3 For each subblock pair:
       - 4.2.3.1 If the subblock pair contains the qualified significant wavelet coefficients (i.e., each value in the subblock is greater than the median value of the corresponding subband)
         Calculate the changes to the subblock pair:

$$Texture = \lambda \times Var \times \frac{\text{power spectrum of the subblock}}{\text{power spectrum of the subband}} \quad \text{where} \begin{cases} \lambda = 1/16 \text{ if level} = 3; \\ \lambda = 1/256 \text{ if level} = 2. \end{cases}$$

else $Texture = 1$

4.2.3.2 /***** Consider all the possible insensitivities of the human eyes *****/

Calculate the overall changes to the subblock pair:

$$BlockChange = \alpha \times \beta \times 0.16 \times Brightness \times Texture$$

$$\text{where } \alpha = \begin{cases} 1 \text{ when level} = 3; \\ 2 \text{ when level} = 2. \end{cases} \text{ and } \beta = \begin{cases} 1 \text{ when direction} = \text{horizontal or vertical} \\ \sqrt{2} \text{ when direciton} = \text{diagonal} \end{cases}$$

4.2.3.3 The *BlocklChange* is recorded at the corresponding positions of the *TotalChange*, which stores the possible changes in the middle frequency subbands.

5. The pseudo-random binary sequence generated from the binary image is rearranged in three different ways to be embedded in the LH3, HL3, HH3, LH2, HL2, and HH2 using the pixel-wise computation:

   $$WatermarkedSubbandValue = OriginalSubbandValue + \omega \times (TotalChange * PseudorandomSequence)$$

   where ω determines the change magnitude; * and + represent the pixel-wise multiplication and addition.
6. Apply the IDWT (Inverse Discrete Wavelet Transform) using the newly updated subband values at the level 3 and level 2 to obtain the watermarked image.
7. Calculate the detection correlation thresholds for level 2 and level 3 subbands by using the corresponding three different rearranged pseudo-random binary sequences and save them for watermark detection.

   Level 2 detection correlation threshold:

   $$T_1 = \frac{sum(FineSequence1 * LH2) + sum(FineSequence2 * HL2) + sum(FineSequence3 * HH2)}{\text{Total Pixel Numbers in the Three Subbands}}$$

   Level 3 detection correlation threshold:

   $$T_2 = \frac{sum(Sequence1 * LH3) + sum(Sequence2 * HL3) + sum(Sequence3 * HH3)}{\text{Total Pixel Numbers in the Three Subbands}}$$

   where LH2, HL2, HH2, LH3, HL3, and HH3 represent the original subband values; * represent the pixel-wise multiplication; and *sum* is a function to calculate the total of a matrix.

B. Watermark Detection

Watermark detection is accomplished without referring to the original image. The correlations R_1 and R_2 between the DWT coefficients and the watermarking sequence to be tested at level 2 and level 3 are computed by using the formula in the last step of the watermark embedding algorithm. These two correlations are compared to the two thresholds T_1 and T_2 saved in the watermark embedding procedure. The watermark is present if and only if one of the following conditions is true:

$$\text{Condition 1}: R_1 > T_1 \text{ and } R_2 > T_2$$

$$\text{Condition 2}: R_1 < T_1 \text{ and } R_2 < T_2$$

III. Experimental Results

The watermark invisibility is shown in Fig. 1 where the original image and the watermarked image are displayed. The scaled difference between the original image and the watermarked one is also demonstrated in Fig. 1. This difference image illustrates the added hidden watermark in the spatial domain. It is evident that the watermark is mainly embedded in the high activity regions and around the edges, which is consistent with the insensitivity of the HVS.

Our proposed algorithm has been extensively tested on various standard images. Table I summarizes the watermarking results in terms of the PSNR (Peak Signal-to-Noise Ratio) and the correlation and threshold values used in the detection procedures. The PSNR of each watermarked image is greater than 35db, which is the empirical value for the image without any perceivable degradation.

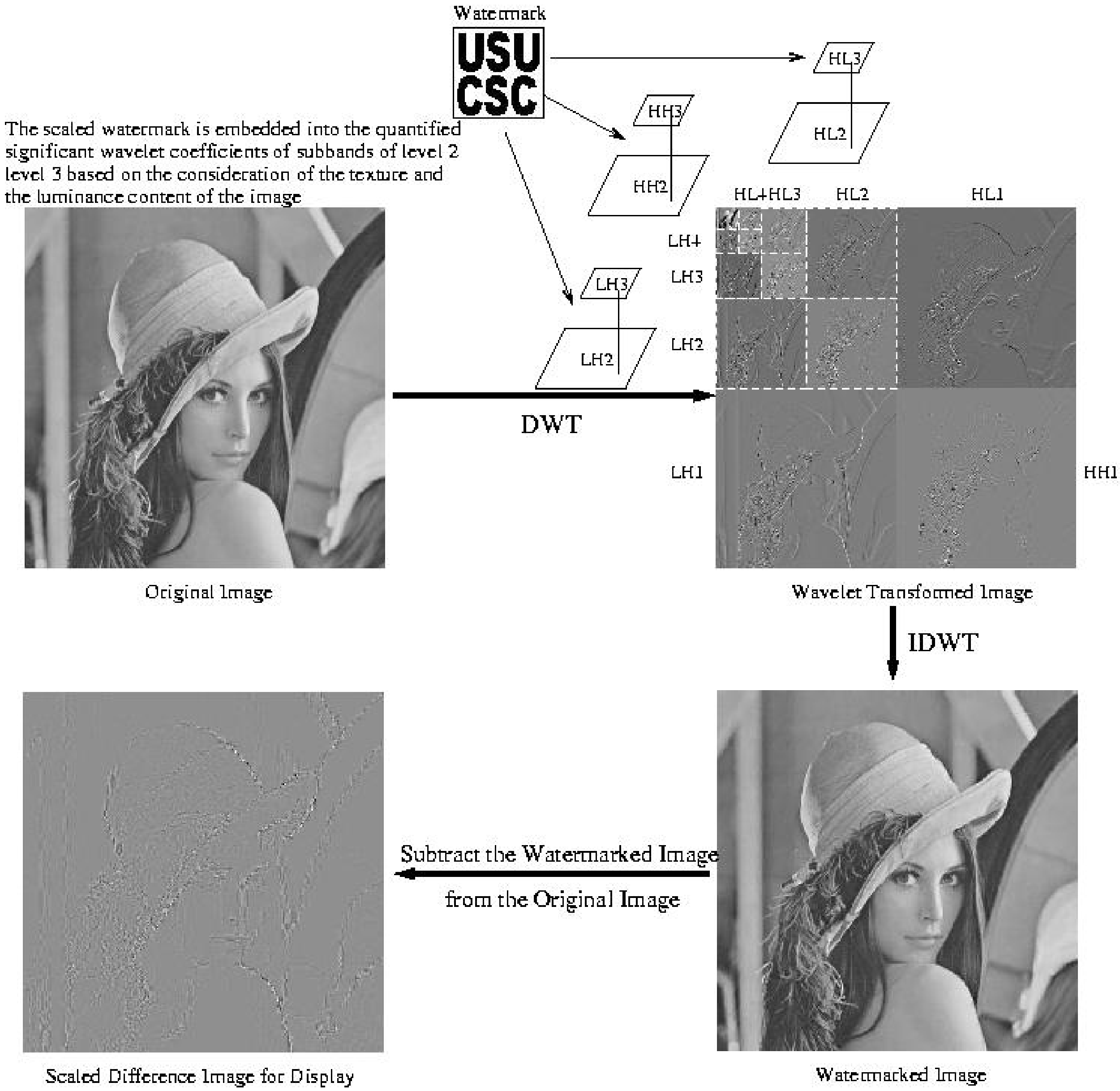

Figure 1: Block Diagram of the Watermark Embedding

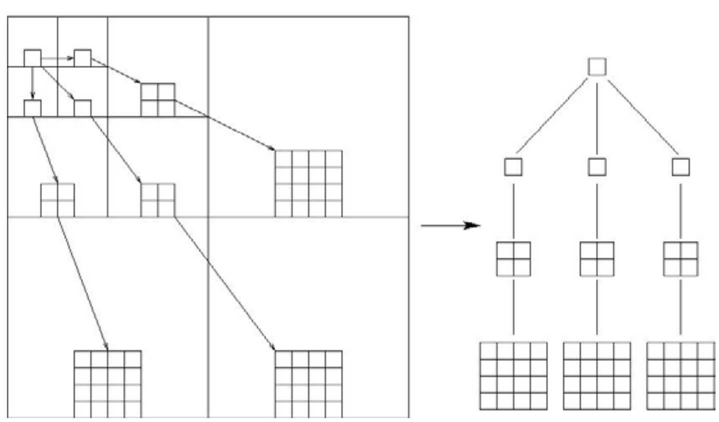

Figure 2: Parent-child Dependencies of 2-D Dyadic 3-Level Wavelet Decomposition

Table I: Watermark Embedding and Detection

Images	PSNR	R1	T1	R2	T2	True Condition	Detection
Lena	38.7948	0.0249	0.0257	0.1759	0.2904	2	Yes
Pepper	35.6447	0.0781	0.0989	0.1473	0.2157	2	Yes
Boat	36.1027	0.0614	0.0080	0.2149	0.1199	1	Yes
Hotel	35.8971	0.1540	0.0803	0.1605	0.0950	1	Yes

Table II shows the detection results from several JPEG-compressed versions of the watermarked Lena image with compression ratios of 2.5:1, 3.3:1, 5:1, 10:1, 12.5:1, 25:1, and 50:1. The correlations between the compressed watermarked image and the digital watermarking code across the level 2 and level 3 are compared with the two thresholds computed during the watermark embedding procedure. The two conditions specified in the watermark detection procedure are used to detect the presence of the watermark.

Table II Robustness against the JPEG Lossy Compression on Lena Image using JPEG Optimizer

Compression Ratios	R1	T1	R2	T2	True Condition	Detection
2.5:1	0.0593	0.0257	0.3184	0.2904	1	Yes
3.3:1	0.0101	0.0257	0.2510	0.2904	2	Yes
5:1	0.0479	0.0257	0.3027	0.2904	1	Yes
10:1	0.0521	0.0257	0.3037	0.2904	1	Yes
12.5	0.0455	0.0257	0.3575	0.2904	1	Yes
25:1	0.0467	0.0257	0.2915	0.2904	1	Yes
50:1	0.0250	0.0257	0.1729	0.2904	2	Yes

Table III shows the detection results of individually applying a certain image processing technique to a watermarked image. These processing techniques include sharpening, median filter smoothing, mean filter smoothing, image resizing (i.e., shrinking and enlarging), and geometric operation.

Table III Robustness against Certain Image Processing Technique on Lena Image

Processing	R1	T1	R2	T2	True Condition	Detection
Sharpening	0.0308	0.0257	0.3248	0.2904	1	Yes
Median Smoothing	0.0287	0.0257	0.3042	0.2904	1	Yes
Mean Smoothing	0.3394	0.0257	1.8601	0.2904	1	Yes
Shrink (2:1)	0.0426	0.0257	0.7109	0.2904	1	Yes
Shrink (4:1)	0.4148	0.0257	4.6362	0.2904	1	Yes
Enlarge (2:1)	0.0046	0.0257	0.0372	0.2904	2	Yes
Enlarge (4:1)	0.0013	0.0257	0.0690	0.2904	2	Yes
Rotate (30)	0.0675	0.0257	0.3205	0.2904	1	Yes
Rotate (45)	0.0734	0.0257	0.3576	0.2904	1	Yes
Rotate (90)	0.1412	0.0257	0.7289	0.2904	1	Yes
Rotate (180)	0.0533	0.0257	0.3283	0.2904	1	Yes

IV. Conclusions

This paper presents a new technique for embedding a binary logo (i.e., watermark) into the DWT of an image. The embedding approach considers the parent-child dependencies among the qualified significant DWT coefficients across the level 3 and level 2 wavelet decompositions. Furthermore, the texture and the luminance content of the qualified significant coefficient pairs at level 3 and level 2 are taken into account to ensure the invisibility of the embedded watermark in accordance with the sensitivity of the HVS. The correlations between the DWT coefficients and the rearranged pseudo-random sequences generated from the binary logo at level 3 and level 2 are calculated and stored as side information. The detection approach compares the corresponding correlation with the side information to determine the presence of the watermark. The experimental results show that the proposed method is robust against JPEG compression and a variety of image processing techniques.

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