

Statistical Image Watermarking In DWT with Capacity Improvement

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Abstract- Abundant techniques has been widely used to design robust image watermarking schemes but in most cases due significance is not given on capacity and data imperceptibility aspects. Robustness of an image-watermarking scheme is the ability to detect the watermark after intentional attacks and normal audio/visual processes. This paper proposes a well-organized blind watermark detection scheme using DWT coefficients. Discrete Wavelet Transform (DWT) is widely applied to image watermarking applications because it decomposes a cover image into spatial domain as well as frequency domain simultaneously. The proposed method improves the capacity of image watermarking. The proposed paper concentrates on some of the main attributes necessary for image watermarking. They are embedding scheme, maximum likelihood detection, decision threshold, and the Laplacian model for image watermarking. The embedding method is multiplicative and done at second level of DWT decomposition by most favorable choice of the embedding strength. The watermark detection is based on the maximum likelihood ratio. Neyman-Pearson criterion is used to reduce the missed detection probability subject to a fixed false alarm probability. The DWT coefficients are assumed to be modeled using the Laplacian distribution. The proposed method is tested for imperceptibility, robustness, and capacity and proved to have better robustness and better imperceptibility and better capacity than other conventional watermarking techniques that were proposed earlier in literature.

Keywords- Decision Threshold, DWT, Laplacian Distribution, Maximum Likelihood Detection, Neyman-Pearson Criterion, Watermarking.

I INTRODUCTION

Multimedia can be defined to be the combination and integration of more than one media format (e.g., text, graphics, images, animation, audio and video) in a given application. Nowadays, multimedia data is stored in the digital form which makes the processing and storage easy. But this leads to unauthorized duplication of the digital data. Digital watermarking is used to solve the above problem. The following requirements are generally considered for to evaluate a watermark system. They are readability, security, imperceptibility, and robustness [14]. It deals with techniques to embed the copyright information into a digital media by making small changes in the media content.

A digital watermark is a prototype of bits inserted into a digital image, an audio or video file. The name comes from the hardly visible text or graphics embossed on stationery that identifies the manufacturer of the stationery. There are

more than a few proposed or actual watermarking applications [12]: broadcast monitoring, owner identification, proof of ownership, transaction tracking, content authentication, copy control, and device control. Specifically, watermarking appears to be useful in plugging the analog hole in consumer electronics devices [13].

Watermarking can be done in either spatial domain or transform domain. Spatial domain approaches like LSB technique are not content based and are simple to implement. Transform domain approaches are more robust and can be implemented adaptively. Among the transform domain, techniques DCT and DWT are commonly used. In [17] [18] [20], for example, the most significant DWT coefficients are selected and modified to carry the watermark. In DWT-based watermarking, the DWT coefficients are modified to embed the watermark data. Because of the conflict between robustness and transparency, the modification at a given level is usually made in HL, LH, and HH sub bands. Additionally, discrete wavelet transform (DWT) based watermarking techniques are gaining more recognition because DWT has a number of advantages over other transform such as progressive and low bit-rate transmission, quality scalability and region-of-interest (ROI) coding stipulate more competent and adaptable image.

The embedding of watermark in the cover image can be done either by additive or multiplicative rule. Usually, for additive embedding, correlation detection is used to detect the watermark. Additive methods are simple and used widely. Non-additive methods are very efficient because of their ability to achieve image dependent embedding and flexibilities in using HVS models. The security of a watermark can be defined to be the ability to prevent hostile attacks such as unauthorized removal, unauthorized embedding, and unauthorized detection. The comparative importance of these properties depends on the requirements of a given application.

For non-additive schemes in DWT domain [1] and [2] suggest Maximum likelihood detection using Bayes Decision theory and Neyman-Pearson criterion for detection. [4] [5] discuss statistical detections in DFT and DCT domain respectively. In paper [1] and [3], third level decomposition is employed and sub bands LH3, HL3 and HH3 are embedded with watermarks. In this paper, we use the level 2 decomposition and embed only in HH2. This improves the payload and imperceptibility. To achieve maximum protection, the watermark should be: 1) undeletable; 2) perceptually invisible; 3) statistically undetectable; 4) resistant to lossy data compression; 5)

resistant to common image processing operations; and 6) unambiguous [15].

The remainder of the paper is structured as follows. Section 2 explains our proposed methodology for image watermarking. Section 3 illustrates the experimental results and discussions and Section 4 concludes the paper with fewer discussions.

II METHODOLOGY

Watermarking is done by altering the wavelets coefficients of carefully selected DWT sub-bands. Figure 1 represents the Multi-resolution DWT sub bands of an image.



Fig.1 Multi-resolution sub bands

A. Embedding Scheme

The proposed scheme embeds watermarks by modifying log-scaled singular value of selected coefficients of all sub-bands [16]. In a DWT-based scheme, the DWT coefficients are modified with the data that represents the watermark. Let $X = \{x_1, x_2 \dots x_N\}$ and $Y = \{y_1, y_2 \dots y_N\}$ be the vectors representing DWT coefficients of cover image and watermarked image in the HH2 region. For embedding, a bit stream is transformed into a sequence. This sequence is used as the watermark. In our case, the watermark $W = \{w_1, w_2 \dots w_N\}$ which is chosen from a set M , is embedded into X giving Y . W is inserted into the X by using multiplicative rule,

$$y_i = x_i(1 + \alpha_i w_i) \quad i = 1, 2, \dots, N$$

where α_i is the embedding strength and x_i, w_i and y_i are the values of the random variable X_i, W_i and Y_i whose Probability Distribution Functions (PDFs) are $f_{X_i}(s_i), f_{W_i}(w_i)$ and $f_{Y_i}(y_i)$ respectively for $i = 1, 2, \dots, N$. The elements of the watermarks from the set M are independent and uniformly distributed in the interval $[-1, 1]$.

B. Maximum Likelihood Detection [1]

The watermark detection is based on the maximum likelihood ratio. If $W^* = \{w_1^*, w_2^* \dots w_N^*\}$ is the embedded watermark, we can write $M = M_0 \cup M_1$, where $M_0 = \{W: W \neq W^*\}$ and $M_1 = \{W^*\}$. The null watermark $W = \{0, 0 \dots 0\}$, which indicates that no watermark is embedded, is already included in M_0 .

Two hypotheses can be established as follows:

$$H_0 = Y \text{ has } W^*$$

$$H_1 = Y \text{ does not have } W^*$$

The statistical decision test or watermark presence detection test is interpreted as deciding if the input of the detector in the outcome of the random process with the pdf conditioned to H_1 and H_0 . It compares the ratio between the pdf conditioned to H_1 and the pdf conditioned to H_0 against a threshold as given below.

If the likelihood ratio,

$$l(y) = \frac{f_Y(y/M_1)}{f_Y(y/M_0)} > \lambda \tag{1}$$

where $f_Y(y/M_j), j = 0, 1$ are the conditional pdfs and λ is the decision threshold.

Since $\alpha < 1$, from [4]

$$f_Y(y/M_0) \approx f_Y(y/0) \tag{2}$$

Assuming that the transform coefficients are statistically independent, (1) can be expressed as

$$l(y) = \frac{\prod_{i=1}^N f_{Y_i}(y_i / w_i^*)}{\prod_{i=1}^N f_{Y_i}(y_i / 0)} \tag{3}$$

$$= \frac{\prod_{i=1}^N \frac{1}{1 + \alpha_i w_i^*} f_{X_i}\left(\frac{y_i}{1 + \alpha_i w_i^*}\right)}{\prod_{i=1}^N f_{X_i}(y_i)} \tag{4}$$

Since $\log x$ is an increasing function of x , $\log l(y)$ will reach its maximum value when $l(y)$ reaches its maximum. Hence, taking natural log on both sides

$$z(y) = \sum_{i=1}^N \left[\ln f_{X_i}\left(\frac{y_i}{1 + \alpha_i w_i^*}\right) - \ln f_{X_i}(y_i) \right] \tag{5}$$

where $\lambda' = \ln \lambda + \sum_{i=1}^N \ln(1 + \alpha_i w_i^*)$ is the modified decision threshold.

C. Decision Threshold [1]

The Neyman-Pearson criterion is stated in terms of certain probabilities associated with a particular hypothesis test. Neyman-Pearson criterion is used to reduce the missed detection probability subject to a fixed false alarm probability. The Neyman-Pearson criterion is used to find λ' to minimize the missed detection probability for a fixed false alarm probability, PFA. PFA is fixed as 10^{-9} .

$$P_{FA} = P(z(Y) = \lambda'/M_0) = P(z(X) > \lambda')$$

$$= \int_{\lambda'}^{\infty} f_{z(x)}(z(x)) dz(x) \tag{6}$$

As the number of Z(x) is more than 30, central limit theorem can be applied and PDF of Z(x) can be assumed to be Gaussian.

Thus,

$$P_{FA} = \int_{\lambda'}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2_{z(x)}}} e^{-\frac{[z(x)-\mu_{z(x)}]^2}{2\sigma^2_{z(x)}}} dz(x) \tag{9}$$

which gives $\lambda' = \text{erfc}^{-1}(2P_{FA}) \sqrt{2\sigma^2_{z(x)}} + \mu_{z(x)}$

D. Laplacian Model [1]

The DWT coefficients are assumed to be modeled using the Laplacian distribution. Each of the DWT coefficients is modeled by the Laplacian PDF given below

$$f_{X_i}(x_i) = 0.5 b_i \exp(-b_i |x_i - \mu_i|) \quad -\infty < x_i < \infty \tag{10}$$

with $b_i = \sqrt{2}/\sigma_i$ where σ_i^2 is the variance of X_i and μ_i is the mean of X_i . Substituting (10) in (4),

$$z(y) = \sum_{i=1}^N b_i \left[|y_i - \mu_i| - |1 + \alpha_i w_i^*|^{-1} |y_i - \mu_i - \mu_i \alpha_i w_i^*| \right] > \lambda' \tag{11}$$

Mean and variance are derived to be

$$\mu_{z(x)} = \sum_{i=1}^N [1 - |1 + \alpha_i w_i^*|^{-1} \{b_i |\mu_i \alpha_i w_i^*| + \exp(-b_i |\mu_i \alpha_i w_i^*|)\}] \tag{12}$$

and

$$\sigma_{z(x)}^2 = \sum_{i=1}^N [1 + |1 + \alpha_i w_i^*|^{-2} \{2 - \exp(-2b_i |\mu_i \alpha_i w_i^*|) - 2|1 + \alpha_i w_i^*|^{-1} \exp(-b_i |\mu_i \alpha_i w_i^*|) - 2b_i |\mu_i \alpha_i w_i^*| \exp(-b_i |\mu_i \alpha_i w_i^*|) \{ |1 + \alpha_i w_i^*|^{-1} + |1 + \alpha_i w_i^*|^{-2} \} \}] \tag{13}$$

Substituting (12) and (13) in (9) the decision threshold λ' is obtained.

III EXPERIMENTAL RESULTS AND DISCUSSIONS

Experiments are performed to prove that the proposed scheme has the robustness against to a wide range of attacks such as JPEG compression, Gaussian noise addition, median filtering, blurring, shift, and rotation. Images of Lena, and Crowd at the size of 512 x 512 are used, as shown in Fig. 1. Lena contains little detail; and crowd contains a large amount of detail [6].



Lena Crowd

Fig.1 Test Images

Digital image watermarks can be detected in the transform domain using maximum-likelihood detection, whereby the decision threshold is obtained using the Neyman-Pearson criterion. Each image is transformed by DWT. Generally, in a two-dimensional DWT, each level of decomposition produces four bands of data denoted by LL, HL, LH, and HH. The LL sub-band can further be decomposed to obtain another level of decomposition. This process is continued until the desired number of levels determined by the application is reached [19]. In our experiments a Daubechies filter is used to obtain a third and a second level decomposition. In the third level decomposition, embedding is done in the high frequency sub bands LH3, HL3 and HH3. Total number of coefficients after combining the three bands is $N = 12,288$. If a coefficient belongs to the particular band, mean μ_I and variance σ_i^2 are estimated from the equations,

$$\mu_i' = \frac{1}{N_B} \sum_{i=1}^N y \tag{14}$$

$$\sigma_i^2 = \frac{1}{(N_B - 1)} \sum_{i=1}^N (y - \mu_i')^2 \tag{15}$$

where $N_B = 4096$ (Number of coefficients in one band). Y is the DWT coefficient in band B of the watermarked image. $\alpha = 0.3$.

The results of detection are listed in Table I.

Image	PSNR for $\alpha=0.3$	Number of successful detections for level III embedding for 10 trials					
		Gaussian noise	Mean filter	Blur	Rotation	JPEG Compression	Crop
Lena	37.24	10	10	5	0	10	10
Crowd	30.89	10	10	9	0	10	10

scheme has the robustness against to a wide range of attacks such as JPEG compression, Gaussian noise addition, median filtering, blurring, shift, and rotation. Images of Lena, and Crowd at the size of 512 x 512 are used, as shown in Fig. 1. Table I contains the number of successful detections for some standard attacks on the watermarked images. Gaussian noise has zero mean and variance 0.5. Blurring is caused by circular filter of the size 31 x 11.

Rotation is upto 10° in the counter clockwise directions. JPEG compression is done to offer 50% quality. Cropping is done to obtain an image whose size is 300 x 300. Mean filter filters the image by using adaptive wiener filter, using neighborhoods of size 4 x 4.

The embedded watermark is chosen from a set of 100 randomly generated watermarks of length N. Number of trials is 10.

In the second level of decomposition, embedding is done only at HH2. Total number of coefficients in HH2 is 16,384. μ and σ^2 are calculated only for this band using 14 and 15. $\alpha = 0.5$ and PFA = 10^{-9} . The results of detection are listed in Table II.

Table II

Image	PSNR for $\alpha=0.5$	Number of successful detections for level II embedding for 10 trials					
		Gaussian noise	Mean filter	Blur	Rotation	JPEG Compression	Crop
Lena	44.97	9	10	10	10	10	10
Crowd	40.63	10	10	10	10	10	10

Comparing Table I and II, we observe that Level II HH2 embedding better imperceptibility and better robustness. Also its capacity is better. Table III lists the PSNR value of level III embedding for different images.

TABLE III

Image	PSNR for $\alpha = 0.5$	PSNR for $\alpha = 0.3$
Lena	32.00	37.24
Crowd	26.49	30.89

IV CONCLUSION

Watermarks and watermarking techniques can be divided into various categories and in various ways. The indispensable and most frequently used partitioning of image watermarking is the spatial domain, transform

domain, and parametric domain watermarking. The embedding of watermark in the cover image can be done either by additive or multiplicative rule. This paper proposed an efficient blind watermark detection scheme using DWT coefficients. A maximum likelihood detection scheme based on Laplacian modeling of coefficients of DWT transformation is implemented. The results obtained at level II, HH2 sub-band embedding are better than the results obtained using the existing method of embedding at level III. The proposed method is tested for imperceptibility, robustness and capacity and proved to have better robustness and better imperceptibility and better capacity than other conventional watermarking techniques that were proposed earlier in literature. In future this can be extended by implementing other statistical modeling.

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