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Performance Evaluation of OFDM Based Watermarking Robust to Multipath Spatial Shifts

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Abstract: A digital watermark is a visible or invisible pattern embedded in a digital image which can be used for copyright protection, authentication, broadcast monitoring, telemedicine and many more. This paper describes how an efficient CDMA based spread spectrum technique can be combined with the most prominent spectrum efficient OFDM technology to formulate a robust watermarking algorithm which is suitable for image distortions due to time delays and spatial shift that may occur during the transmission of watermarked images. A detailed simulation of embedding and decoding algorithm was performed and compared the performance with the existing DCT, DWT and FWHT based techniques. Simulation results reveal that the proposed algorithm is computationally efficient, robust and is well suited for wireless multipath fading channel. The algorithm was tested against a number of possible noises in the wireless channels and various geometric and signal processing operations. The proposed algorithm is proved to be robust enough to extract a good quality watermark compared to well-known techniques.

Keywords: Watermarking, OFDM, Robust, Multipath, Distortion

1. Introduction

The rapid growth of wired and wireless technologies has brought forward novel, easy and fast ways of real time information exchange, business, entertainment and advertising. With those advanced digital technologies, shared and transmitted multimedia signals can easily be downloaded, copied and manipulated. There should be proper ways to counteract this illegal access and manipulations. Watermarks are specific pattern of bits which can be embedded in the multimedia signal, whose integrity is to be maintained and protected. The watermark can be embedded in an image by modifying the two dimensional pixel values (spatial domain watermarking) or by transforming the image to another domain such as frequency domain (transformed domain watermarking) [1]. Usually, image is transformed to frequency domain using transforms like Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT), Fast Walsh Hadamard Transform (FWHT) or Fast Fourier Transform (FFT) [2][3][4] and the selected frequency coefficients are modified in accordance with the embedding algorithm. Compared to the spatial domain techniques, though the frequency domain techniques are complex they are more robust and secure. So according to the requirements, complexity can be compromised for increased robustness and vice versa. The fundamental properties of watermarks are data hiding capacity, imperceptibility and robustness [4][5]. The embedding algorithm should be able to embed the watermark without affecting the perceptual transparency of the original cover image. As the number of watermark bits in the image, to be protected increases, the more robust will be the watermark against attacks. But at the same time, the increased number of watermark bits cause considerable reduction in the perceptual quality. Thus, the watermark system should accept the trade-off among the properties according to the applications [3].

Watermarking has various applications like authentication, copyright protection, broadcast monitoring (Ensuring the proper broadcast at the proper timing), transaction tracking/ finger printing (Finding out the source of leakage of multimedia signal), medical applications, etc.,[2]. Based on the applications, the embedding and decoding algorithm should be modified. Just like communication system, the watermarked multimedia signal is susceptible to various types of attacks. These can be non-intentional attacks such as geometrical and signal processing manipulations on the image or malicious attacks such as collusion, confusion or ownership deadlock [6]. The information sent through the high-speed wireless channel is susceptible to various types of distortions such as multipath fading, noise and co-channel interference. Watermarks should be able to withstand some or all of these attacks.

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Watermarking system can be compared to a communication system and all the techniques which we use to make the watermarking system more secure and robust can also be employed equally in watermarking scenarios as well. As CDMA based spread spectrum technique is considered to be the most secure and efficient communication system in which the message (watermark) is spread throughout the wide bandwidth of the carrier (cover image) and thus impart better robustness and security against attacks and distortions [2]. The watermark is spread using orthogonal spreading codes such as gold code or Hadamard code and is added to the frequency domain coefficients of the cover image [7][8]. The coefficients where the watermarks to be added should be selected properly in such a way that the watermark bits will not be lost after compression and the bit error rate of the recovered watermark at the decoding side is minimum [3]. At the same time, orthogonal frequency division multiplexing (OFDM) is used to minimize the multipath fading in the wireless channel. OFDM converts the signal into different sub bands and each part is modulated on orthogonal carriers [9]. As the carriers are orthogonal in nature, the modulated signal can be overlapped and transmitted without much distortion, which in turn offers the benefit of reduced bandwidth compared to the other techniques. The OFDM is done by applying inverse Fast Fourier Transform (IFFT) to the signal. As the narrow band interference affects only a fraction of the sub-carriers a considerable amount of robustness can be easily accomplished using OFDM. Nevertheless, OFDM is more resistant to impulse noise and speckle noise because of the spreading effect of the Fast Fourier Transform. Thus to make use of the increased robustness and reduced multipath fading of the OFDM techniques, the watermark embedding is done using IFFT and decoding is done by applying FFT to the received signal.

OFDM based watermarking has drawn the attention of researchers recently. Even though some papers proposed the OFDM based approach for watermarking, they have failed to demonstrate the robustness of the proposed algorithm [9][10][11]. Masaki Hakka et.al, formulated an OFDM based watermarking algorithm, robust against only clipping attacks [12]. Somnath Maiti et.al, have demonstrated the robustness of the presented algorithm only for few distortions [13]. In this paper intensive simulations have been done on most of the noises and distortions. Moreover the paper considered the effect of spatial shift caused by multipath fading and proved that the proposed algorithm is robust to multipath spatial shifts which are not considered in any of the existing papers. Most of the DCT and DWT based mid-band spread spectrum based algorithms fail to retrieve the watermark in such scenarios. So the proposed technique can be used in situations where image gets spatially shifted and get added up or in situations where the images are transmitted through a multipath fading channel as in telemedicine.

This paper is organized as follows. Section II describes the shift invariant property of FFT. Section III explains the proposed algorithm of embedding and decoding followed by the simulation results in Section IV and finally, Section V concludes the paper. Mainly we used, three different cover images and three different watermarks for analysis as shown in succeeding sections.

2. Shift Invariant Property of FFT

The FFT of a one dimensional signal x(n) of length N is given by the equation

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-2\pi kni}/N \qquad (1)$$

where k = 0 to N -1

The FFT of the signal x(n), after shifting it by a value n_0, $x(n-n_0)$ is given by

$$FFT(x(n-n_0) = X(K)\, e^{-2\pi k n_0}/N \qquad (2)$$

From equation 3 it can be noted that the magnitude of the FFT coefficients is not changed when the original signal is shifted in the original domain. The shift in the time or spatial domain cause only changes in the phase of the resultant signal. Utilizing this fact, if the watermark is embedded in the magnitude of the FFT coefficients, the shift in the watermarked image does not impart much change to the embedded watermark and thus it can be extracted without much error from the attacked (shifted) watermarked image.

3. Proposed Algorithm

In this paper a new watermarking algorithm which makes use of the prominent OFDM technology is proposed.

$$\begin{matrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & - & - & - & - & 1 & 1 \\ 1 & 1 & - & - & - & - & 1 & 1 \\ 1 & 1 & - & - & - & - & 1 & 1 \\ 1 & 1 & - & - & - & - & 1 & 1 \\ 1 & 1 & - & - & - & - & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix}$$

Figure. 1 Matrix *H* for location of watermark embedding.

A. Embedding Algorithm

1) *Decompose the host image,C, into k number of 8×8 blocks,i_k.*
2) *Find the IFFT of each of the blocks. IFFT of k^{th} block is given by*

$$h_k = IFFT(i_k) \qquad (3)$$

3) *Shift the DC coefficients and low frequency coefficients to the middle of each block.*
4) *Convert the watermark, W, into one dimensional string ((b1,b2,b3….,bn).*
5) *Generate two PN codes for spreading, PN_0 (for bit 0) and PN_1 (for bit 1)*
6) *Fig 1 shows the location of watermark embedding in each block as a matrix H. The coefficients in the positions marked with 1 are only modified and rest of the coefficients are left unchanged. Coefficients are selected in such a way that, the changes made to them do not make much impact on the visible quality of the cover image and the bit error rate at the decoding side are also kept to a minimum. For k^{th} transformed block, the absolute value of the coefficients at the locations marked with 1 in H are modified using (4)*

$$\overline{W_k} = h_k(H) + \alpha PN_u \quad (4)$$

Where $PN_u = PN_0$ if $b_x = 0$, $PN_u = PN_1$ if $b_x = 1$, $h_k(H)$ are the IFFT coefficients at which the matrix H had 1's and α is the gain of embedding. $\overline{W_k}$ is the IFFT of the k^{th} watermarked block.

7) *Repeat the above step for all the blocks such that each bit of the watermark is embedded in each of the 8×8 blocks.*
8) *Find the FFT of each block.*

$$W_k = FFT(\overline{W_k}) \quad (5)$$

9) *Reconstruct the watermarked image by combining all the blocks, W_k in one matrix which is of the same size as the original cover image*

B. Decoding Algorithm

Once the watermarked image is received at the decoder, the watermark is extracted from it using the following steps

1) *Decompose the watermarked image into 8x8 blocks.*
2) *Find the IFFT of each of the blocks.*
3) *Generate the same PN codes PN_0 and PN_1 just as in the encoder side.*
4) *For each transformed block, extract the absolute value of the frequency coefficients at locations marked with 1 in Fig. 1 to a one dimensional matrix.*
5) *Find out the correlation of the extracted matrix in Step 4 with each of the PN sequences. If correlation value with PN_1 is high, then the embedded bit is assumed to be 1 or else it is assumed to be 0.*
6) *Step 5 is repeated for all the blocks and the watermark is extracted*

Fig. 2 shows the embedding and decoding procedure in the case of a 512×512 cover image, watermarked with 45×23 pixel watermark. As shown the watermarked image is perceptually not different from the cover image and embedded watermark can be extracted without any error at the decoding side.

4. PERFORMANCE EVALUATION AND SIMULATION RESULTS

The performance of the algorithm is measured and compared based on the following metrics. Mean Square Error (MSE), is the measure of the deviation of watermarked image from the original cover image, which is given by,

$$MSE = \frac{1}{mn}\sum_{i=1}^{n}\sum_{j=1}^{m}(C(i,j) - WI(i,j))^2 \quad (6)$$

Where C is the original cover image intensity, WI is watermarked image Intensity, m and n are the width and height of the cover image. Peak Signal to Noise Ratio (PSNR) is the measure of similarity of the original cover image and the watermarked image. It is the direct measure of perceptual quality.

$$PSNR = 20\log\frac{(\max(\max(C))}{\sqrt{MSE}}$$

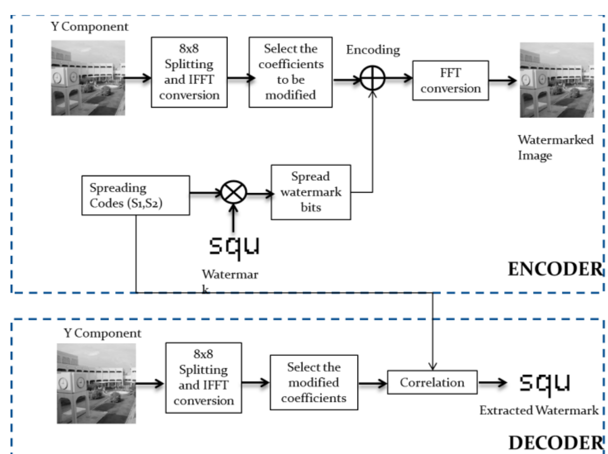


Figure. 2 Embedder and Decoder output.

To quantify the quality of the extracted watermark the Bit Error Rate (BER) is used as indication of the similarity of the original binary watermark and extracted watermark. The BER counts the bit by bit difference between the original watermark and the extracted watermark, thus indicating the efficiency and robustness of the watermarking algorithm against image distortions and attacks.

A. Computational Complexity and Execution time

As there exists fast algorithmic implementations for calculating the Fast Fourier transform, the computation time for embedding and decoding are very less compared to other similar existing algorithms which make use of DCT and DWT. High speed, real time hardware implementation of FFT and IFFT is possible using digital logic, field programmable gate arrays, etc. The constraint of serial execution of software implementation is generally overcome by the parallel processing capability of the hardware which improves the throughput considerably [14]. The total time taken for embedding and decoding a 32×32 size watermark in a 512×512 Lena image using the proposed technique is measured to be 1.123422 seconds on HP Laptop EliteBook 8470p with Windows 7 Operating System, 8 GB RAM and Intel i5 core CPU with a clock speed of 2.8 GHz which is considerably less compared to the similar DCT and DWT based algorithms (2.76 seconds and 16.93 seconds respectively) [5][7].

As the embedding gain increases, the amount of watermark content in the image increases and thus the visual quality of the image decreases as shown in Fig. 4. At a gain of 0.1, watermarked image has a PSNR value of 56 dB and at a gain of 15 it has a PSNR value of 14 dB. The proposed algorithm is capable of yielding a good quality watermark at the extractor even at a small embedding gain. At a gain of 0.6, the algorithm yields a watermarked image of PSNR value 40.8 dB and at the extractor, watermark of BER as low as 0.9 % can be extracted from the watermarked image. So the algorithm in effect produces a watermarked image with high perceptual quality, yielding better extracted watermark with low BER.

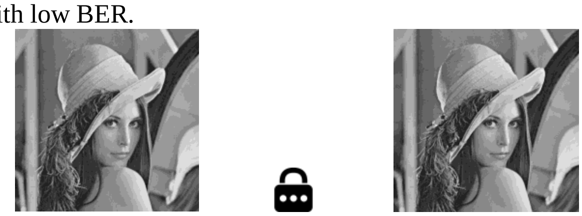
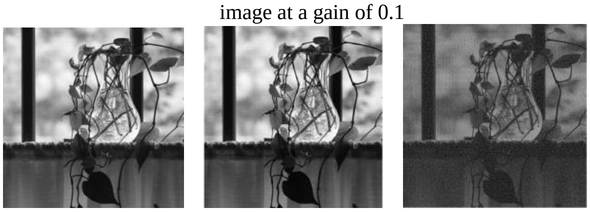


Figure. 3 a) Original Lena image b) Watermark c) Watermarked image at a gain of 0.1



(a) (b) (c)

Figure. 4 Plant image a) Original b)Watermarked at a gain of 0.1 c) Watermarked at a gain of 15

When we compare with the computationally efficient mid-band technique using Fast Walsh Hadamard Transform (FWHT) [15], in the same testing environment as explained above, the time consumed is only slightly greater in the case of the proposed technique (1.05 seconds and 1.12 seconds respectively). But when we compare the perceptual quality of both the technique, the proposed technique shows far better perceptual quality without any square shaped visual artifacts which is present in the FWHT based technique. So Human Visual System cannot perceive much visual degradation even at a very high embedding gain. Even for DCT technique [3] this block wise artifact is present which is not there in FFT based technique. Fig.5 shows the zoomed version of watermarked images at a PSNR value of 30.5dB in the case of FWHT, DCT and proposed technique respectively. From the figures it is evident that the proposed technique shows better quality at the same PSNR value compared to other technique.

Figure. 5 Zoomed watermarked Lena image (PSNR = 30.5dB) in the case of a) FWHT Technique b) DCT Technique c) Proposed Technique

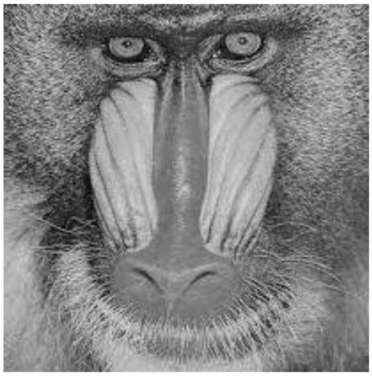


Figure. 6 Baboon Image

When we watermark a complex structured image such as Baboon image shown in Fig 6, the perceptual degradation and the square shaped artifacts will not be much noticeable. But for smooth images like Lena image these degradation in the perceptual quality affects very much. So the proposed algorithm is best suited for smooth structured images where much perceptual quality degradation cannot be tolerated.

B. *Robustness Analysis*

The proposed algorithm is resilient to compression. In TABLE I given below, the extracted 32×32 pixel watermark from 512×512 pixel Lena image for different compression qualities are shown. From the table it is evident that as the compression quality decreases, the BER of extracted watermark increases

TABLE I EXTRACTED WATERMARK AT DIFFERENT COMPRESSION QUALITY

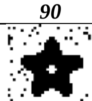
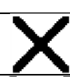
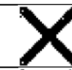
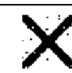
100	***90***	***80***	***70***	***60***
				

TABLE II. EXTRACTED WATERMARK AFTER DIFFERENT ATTACKS

Attacks (Level)	***Recovered Watermark***	***BER of recovered watermark (%)***
Original		0
Scaling(2 times)		2.54
Scaling(4 times)		2.54
Scaling(6 times)		2.54
Sharpen (size - 3×3)		1.3
Sharpen (size -5×5)		0.82
Blur (size - 2×2)		18.88
Blur (size - 3×3)		36.4
Blur (size - 4×4)		50.9
Gaussian Noise (μ=0,σ^2= 0.001)		20.97
Gaussian Noise (μ =0.01, σ^2= 0.001)		20.95
Gaussian Noise (μ =0. 001, σ^2= .001)		17.94
Salt and Pepper Noise (Density=0.001)		2.18
Salt and Pepper Noise (Density =0.01)		20.46
Salt and Pepper Noise (Density =0.1)		38.57
Speckle Noise (Density =0.001)		4.83
Speckle Noise (Density =0.01)		29.2
Speckle Noise (Density =0.1)		47.85
Random Value Impulse Noise (Maximum Value = 20)		7.71
Random Value Impulse Noise (Maximum Value = 30)		19.82
Random Value Impulse Noise (Maximum Value = 40)		30.08

The robustness of the watermarked image against different attacks is analyzed and the BER of the extracted watermark after different attacks are shown in TABLE II. When watermarked images are passed through the wireless channel, it is prone to various sorts of noises such as Additive White Gaussian Noise (AWGN), Salt and Pepper Noise, Random Value Impulse Noise, Speckle Noise etc., [16]. TABLE II shows that the embedded watermark can survive all the above noises and watermark can be extracted accurately at the decoder side. Due to various interferences in the wireless channel, the desired signal (Image) will reach the destination through different paths and the received image at the decoder will be the sum of signals from various paths. If WI is the watermarked image which is transmitted through a fading channel, the received image will be the sum of scaled and shifted versions of the watermarked image,

$$Received\ Image = a_1 * WI + a_2 * WI\ (Shifted) \quad (8)$$

where a_1 and a_2 are scalars that indicate the relative scaling of the different shifts with respect to the un-shifted image.

Fig. 7 shows the image out of a fading channel with $a_1 = 3$ and $a_2 = 2$ with a circular shift of 20 pixels and Fig. 8(a)-(d) show the recovered watermark using the proposed technique (BER = 5.37%), using midband DCT technique (BER = 30.18%), midband DWT technique (BER = 24.22%), midband FWHT technique (BER = 29.7%) respectively. TABLE III below shows the bit error rate (BER) of the received watermark for different values of linear shifts (watermarked image is shifted left replacing the shifted pixel by zeros) and circular shifts applied to (8).

From TABLE III, it is apparent that for all the techniques other than the proposed one, the BER of the extracted watermark is very high even at small shifts. On the other hand the proposed technique can extract the watermark with the best BER compared to all other techniques. It shows the best performance even at high shift values. After passing through the multipath fading channel the distortion caused to the watermark is negligible. On the other hand, existing watermarking techniques which make use of FWHT [15], DCT [3][18][19], and DWT [20] fail to retrieve the encoded watermark with reasonable BER in the above situations. So the proposed technique is the best computational efficient algorithm which is resistant to multipath space shifts.

Figure. 7 Received Image through a fading channel

(a) (b) (c) (d)

Figure. 8 Extracted Watermark a) using proposed technique b) using midband DCT c) using midband DWT d) using midband FWHT.

TABLE III. BER OF THE EXTRACTED WATERMARK AFTER DIFFERENT SHIFT VALUES

Shift Value	BER (%) of extracted watermark							
	Proposed Algorithm		FWHT		DCT		DWT	
	Circular Shift	Linear Shift	Circular Shift	Linear Shift	Circular Shift	Linear Shift	Circular Shift	Linear Shift
1	2.73	4	29.2	29.3	27.7	29.5	19.43	24.2
5	5.37	3.81	29.3	29.1	24.8	22.9	22.66	24.4
10	5.27	4.39	29.3	29.4	30.18	24.8	24.02	21
15	8.98	4.88	29.4	29.4	31.8	22.5	19.92	27.2
20	5.37	6.54	29.7	29.5	30.18	27.2	24.2	22.1
25	9.08	5.47	29.5	28.7	31.15	26.8	19.9	27.2
30	8.79	4.3	29.5	29.2	29.7	26.6	22.9	20.8
35	8.89	4.1	29.6	29.3	28.61	27.3	24.7	24.3

5. CONCLUSION

This paper did a detailed investigation of digital image watermarking, its various properties and applications. In addition, proposed a new digital image watermarking algorithm, with low computational complexity and which makes use of the benefits of CDMA and OFDM technology. Intensive simulation results of the possible attacks and distortions were also presented. Embedded watermark is capable of surviving most of the distortions and attacks under consideration. Use of OFDM technology makes the system resistant to spatial shifts that may occur in multi path fading environments. A detailed comparison with the existing DWT, FWHT and DCT based techniques have been performed. The algorithm is capable of extracting low Bit Error Rate (BER) watermark even at low embedding gain while keeping the perceptual quality at an acceptable level.

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