A Novel Digital Watermarking Method Based on Multi-Level DWT and New Class of Reciprocal-Orthogonal Parametric Transforms ROPT

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Abstract— since the second half of the 1990' several works, dealing with image watermarking, have been proposed. The majority of those works are based on the use of transformed (frequency) domain provided by various transforms namely DCT, DFT, DWT…etc. Further, several hybrid techniques have been proposed, among those based on block DCT/DFT and those relying on DWT. through the work presented in this paper, authors propose a new hybrid watermarking method for still and grey scale images. It combines two transforms, namely the multi-level discreet wavelet transform (DWT) decomposition and a new class of reciprocal- orthogonal parametric transforms (ROPT). The basic idea behind the proposed method is to use a new method of generating keys by exploiting the huge number of independent parameters (3N/2) provided by the ROPT as supplement watermarking key added to the one used for inserting the watermark. To get rid of the disadvantage of the ROPT, which gives a non uniform partition of frequencies, the low-pass (LL) sub-band obtained by DWT is used. By this way we ensure on the one hand that the region frequencies in where the watermark will be inserted are all from the same range, on the other hand to ensure the robustness of the watermark against some attacks. Experimental results demonstrate that the proposed method is robust against JPEG compression, low pass filtering, added noise and the combination of these attacks.

Keywords: Digital watermarking, data hiding, still image, DWT, ROPT, JPEG compression, Gaussian noise

I- INTRODUCTION

With the advent of digital technologies for production, storage and distribution of digital media, it became extremely easy to reproduce a data without any loss of information. Unlike copies of analog tapes, copies of digital data are identical to the original and suffer no quality degradation, and there is no limit to the number of exact copies that can be made. In addition, digital equipment that can make digital copies is widely available and inexpensive.

A major problem faced by content providers and owners is copyright protection and others forms of abuse of their digital content. Watermarking presents an alternative which can contribute to enforce intellectual property rights and provides protection of the document content. In order to be useful, the watermark must be robust against a variety of possible attacks by pirates. These include robustness against compression such as JPEG, scaling and aspect ratio changes, rotation, cropping, row and column removal, addition of noise, filtering, cryptographic and statistical attacks, as well as insertion of other watermarks. Researchers have paid great efforts on watermarking techniques, up to now, many watermarking methods have been proposed either in the spacial domain or in the transformed one added to those named hybrid methods[1][2][3][4][5].

In this paper we propose a watermarking scheme for digital image that combines the DWT and a new class of ROPT presented by S.Bouguezel in [6].

The paper is organized as follows. In section II, related works to the hybrid watermarking methods are presented. Section III, presents a related theory about DWT and an overview on the new class of ROPT presented by S.Bouguezel. In section IV, we describe our approach, including watermark insertion and detection procedures. Experimental results are given in section V, and in section VI we conclude the paper.

II- RELATED WORKS

Falkowski and Lim propose a watermarking technique based on multi-resolution and complex Hadamard transforms [7]. Initially the multi-resolution Hadamard transform is applied to the image to decompose it into various frequency bands. The lowest frequency band is then divided into 8x8 blocks and 2D Hadamard transform is applied. Watermark is embedded in this domain by altering the component of the most significant image component. The proposed scheme is shown to be robust against several attacks like JPEG compression, image scaling, cropping and successive watermarking.

Gilani and Skodras proposed a technique in which they embed the watermark by modifying the high frequency Hadamard coefficients [8]. An image undergoes a Haar Wavelet Transform then a Hadamard one. This gives rise to the multi-resolution Hadamard Frequency domain. The Hadamard transform concentrates most of the energy in the upper left corner, and hence it is selected to embed watermark information. The authors argue that high frequency bands of Hadamard transform are robust against noise and hence can resist JPEG compression attacks at low quality factor.

Bogdan J. Falkowski reveals about how to embed a watermark on the grey scale image using multi-resolution modified multi-polarity Walsh-Hadamard transform and complex Hadamard transform [9]. The process is, the raw pixels are extracted from the bit map image and it is stored in two dimensional arrays. Then multi-polarity Walsh-Hadamard transformation is applied to decompose the image into pyramid structure with various sub bands. The lowest frequency sub band is selected and segmented into 8x8 blocks and then apply one dimensional complex Hadamard transformation on the rows followed by columns. Then complex Hadamard transform coefficients are altered and watermark is embedded.. This technique is robust to JPEG encoding, image resizing, dithering, noise distortions, sharpening and cropping.

Gaurav Bhatnagar and Balasubramanian Raman proposed a newer version of Walsh-Hadamard Transform namely multi-resolution Walsh-Hadamard Transform (MR-WHT). Further, a robust watermarking scheme is proposed for copyright protection using MR-WHT and singular value decomposition [10]. The core idea of the proposed scheme is to decompose an image using MR-WHT and then middle singular values of high frequency sub-band at the coarsest and the finest level are modified with the singular values of the watermark. Finally, a reliable watermark extraction scheme is developed for the extraction of the watermark from the distorted image. This technique provides better visual imperceptibility and resiliency against intentional or un-intentional variety of attacks.

Marjuni, A.; Logeswaran, R.; Ahmad Fauzi, M.F.; proposed a new image watermarking scheme based on the Fast Walsh Hadamard transform (FWHT) combined with the Discrete Cosine Transform (DCT) [11]. The digital cosine transformation is applied to each 8x8 block of original image to get the DC coefficients where the original watermark, which undergoes the FWHT, is embedded. Then the inverse discreet cosine transformation is applied on the watermarked DC component to reconstruct the watermarked image. This scheme produces high perceptual transparency of the embedded watermark and is robust against attacks.

Franklin Rajkumar.V, Manekandan.GRS and V.Santhi presented a novel watermarking algorithm in which Hadamard transformation technique is combined with entropy model. This entropy model measure the information content of each block which is used as criterion for selection of blocks [12]. The proposed technique can hide an entire image or pattern as a watermark directly into the original image. As the quality of the image is to be preserved the entire image is not altered for embedding, instead few blocks are used based on the size of the watermark and information content of an image block. The computational complexity of the proposed algorithm is reduced by the use of Hadamard transformation which converts the cover image from spatial domain to transform domain. The proposed scheme is robust to random noise addition attack, resize attack and cropping attack.

III- RELATED THEORY

A- discreet wavelet transforms DWT

The wavelet decomposition decomposes image in high and low pass components with different orientations [13]. The procedure is like follows: the image is decomposed into, four, half-sized, sub-images, called image sub-bands: a low-pass (LL) sub-band resulting in the application of low-pass filtering in both horizontal and vertical directions, two detail sub-bands obtained by applying a low (high) pass filter in the horizontal direction and a high (low) pass one in the vertical direction (LH and HL sub-bands), and a high pass sub-band (HH) obtained by applying a high pass filter in both horizontal and vertical directions. This procedure is then applied again o the low-pass sub-band and iterated until the desired level of decomposition is obtained. An example of decomposing through wavelet filtering is shown in Fig.1.

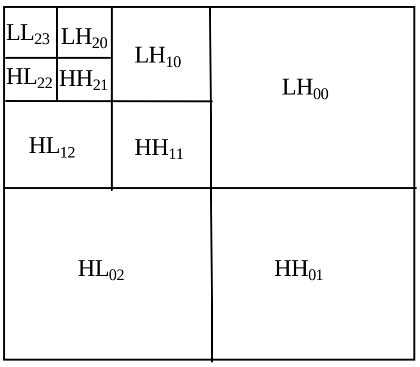


Figure.1 The wavelet pyramid of three level image decomposition

B- Overview on the new class of ROPT

The work proposed by S. Bouguezel in [6] deals with a new class of Reciprocal-Orthogonal Parametric Transforms (ROPT). The idea is based on the combination of a new parametric kernel with that of the well known Walsh-Hadamard transform that results in a square parametric matrix operator of order *N* with some very interesting properties. One of the most important properties of this transform is that the inverse of the matrix operator is the transpose of the matrix whose entries are all reciprocals of the entries of the forward matrix. This Nth-order matrix operator and its normalized version have 3*N*/2 and *N*/2-1 independent parameters, respectively, for a sequence length *N* that is a power of two.

An ROPT of a complex sequence $x(k)$ of order $N=2^r$ is defined as:

$$X(n) = \sum_{k=0}^{N-1} x(k)\, a_{k,s(n)} (-1)^{kon} \;......n = 0,1,.....,N-1 \qquad (1)$$

Where $k\,o\,n = k_0n_0 + k_1n_1 + \dots\dots\dots + k_{r-1}n_{r-1}$, $s(n) = (-1)^{(N-1)on}$.

The inverse of the ROPT defined by (1) is given by

$$x(k) = \frac{1}{N}\sum_{n=0}^{N-1} X(n)\frac{1}{a_{k,s(n)}}(-1)^{kon} \;......k = 0,1,.....,N-1 \qquad (2)$$

Where $a_{k,1}$ and $a_{k,-1}$ are nonzero complex parameters satisfying:

$$a_{k,1}a_{N-1-k,-1} = a_{k,-1}a_{N-1-k,1} \qquad (3)$$

We assume that the input and output sequences $x(k)$ and $X(n)$ are given by the *N*x1 column vectors x and X, respectively. Then, the matrix formulation of the forward and inverse ROPT given by (1) and (2) can be expressed by using new parametric matrices having simple structures with interesting properties given as follow:

$$X = P_N\, x \qquad (4)$$

$$x = P_N^{-1} X \qquad (5)$$

Where P_N and P_N^{-1} are the forward and the inverse matrices of the transform respectively. Discarding the scaling factor $1/N$, it is clear from (1) and (2) that the (k, n)th entry of the matrix P_N^{-1} is the inverse (i.e. reciprocal) of the (n, k)th entry of the matrix P_N. Therefore, the inverse matrix $P_N^{-1}$is easily obtainable from the forward matrix P_N as $1/N(P_N^R)^T$, where the matrix P_N^R is obtained by taking the reciprocal of each entry of P_N and $(.)^T$ represents the transposition of the associated matrix. In view of the fact that P_N satisfies the relation $P_N^{-1}=1/N\ (P_N^R)^T$ and contains all the independent parameters of the transform, it is called an ROP matrix. An ROP matrix is said to be normalized if all the entries in its first row and first column are unity.

The case of $N=8$ leads to the forward ROP matrix given as follows(6).

$$P_8 = \begin{bmatrix} a_{0,1} & a_{1,1} & a_{2,1} & a_{3,1} & a_{4,1} & a_{5,1} & a_{6,1} & a_{7,1} \\ a_{0,-1} & -a_{1,-1} & a_{2,-1} & -a_{3,-1} & \frac{a_{3,-1}.a_{4,1}}{a_{3,1}} & -\frac{a_{2,-1}.a_{5,1}}{a_{2,1}} & \frac{a_{1,-1}.a_{6,1}}{a_{1,1}} & -\frac{a_{0,-1}.a_{7,1}}{a_{0,1}} \\ a_{0,-1} & a_{1,-1} & -a_{2,-1} & -a_{3,-1} & \frac{a_{3,-1}.a_{4,1}}{a_{3,1}} & \frac{a_{2,-1}.a_{5,1}}{a_{2,1}} & -\frac{a_{1,-1}.a_{6,1}}{a_{1,1}} & -\frac{a_{0,-1}.a_{7,1}}{a_{0,1}} \\ a_{0,1} & -a_{1,1} & -a_{2,1} & a_{3,1} & a_{4,1} & -a_{5,1} & -a_{6,1} & a_{7,1} \\ a_{0,-1} & a_{1,-1} & a_{2,-1} & a_{3,-1} & -\frac{a_{3,-1}.a_{4,1}}{a_{3,1}} & -\frac{a_{2,-1}.a_{5,1}}{a_{2,1}} & -\frac{a_{1,-1}.a_{6,1}}{a_{1,1}} & -\frac{a_{0,-1}.a_{7,1}}{a_{0,1}} \\ a_{0,1} & -a_{1,1} & a_{2,1} & -a_{3,1} & -a_{4,1} & a_{5,1} & -a_{6,1} & a_{7,1} \\ a_{0,1} & a_{1,1} & -a_{2,1} & -a_{3,1} & -a_{4,1} & -a_{5,1} & a_{6,1} & a_{7,1} \\ a_{0,-1} & -a_{1,-1} & -a_{2,-1} & a_{3,-1} & -\frac{a_{3,-1}.a_{4,1}}{a_{3,1}} & \frac{a_{2,-1}.a_{5,1}}{a_{2,1}} & \frac{a_{1,-1}.a_{6,1}}{a_{1,1}} & -\frac{a_{0,-1}.a_{7,1}}{a_{0,1}} \end{bmatrix}$$

(6)

IV- PROPOSED APPROACH

In the proposed watermarking approach two transforms are used. Namely, discreet wavelets transform (DWT) and the new class of reciprocal- orthogonal parametric transforms (ROPT) presented by S. Bouguezel in [6] and which is adapted to our application. Indeed, instead of using sequences as input and output we use matrices. Therefore, the ROPT and the inverse ROPT are given by (7) and (8) respectively. We assume that the input and output matrices *y (i,j)* and *Y (u,v)* are of size *N*x*N*.

$$Y= (P_N.\ y.\ (P_N^{R})^{T})/N \qquad (7)$$

$$y =((P_N^{R})^{T}.\ Y.\ P_N/N \qquad (8)$$

The former transform permits to obtain a suitable area for inserting the watermark, in our case the low-pass (LL) sub-band is used, this leads to verify the robustness criteria. The second one provides a supplement security keys added to this or those used for inserting the watermark. Indeed, the choose of parameters of the matrix given by (6) to apply the ROPT to the low-pass (LL) sub-band of the host image are different to those chosen to apply the ROPT to the watermark. The two main phases of the watermarking system which are embedding and extraction process are given by algorithms below.

A- Embedding algorithm

- Convert the host image into gray scale image if it is a color one.
- Apply the DWT at the desired level (d) to the image.
- Divide the low-pass (LL_d) sub-band, obtained by steep 2, into block B_{ij} of size 8x8.
- After choosing the appropriate parameters, whose form the first key, apply the ROPT to each block B_{ij} such as: ROPT $[B_{ij}] = RB_{ij}= (P_N.\ B_{ij}.\ (P_N^{R})^{T})/N$. in our case N=8.
- Divide the watermark, which is an image and should have the same size of the low-pass (LL_d) sub-band, into block W_{ij} of size 8x8.
- After choosing the appropriate parameters, whose form the second key, apply the ROPT to each block W_{ij} such as: ROPT $[W_{ij}] = RW_{ij}= (P_N.\ W_{ij}.\ (P_N^{R})^{T})/N$. always N=8.
- Insert the watermark by combining RB_{ij} and RW_{ij} according to a parameter (λ) of watermarking strength which ensures by one hand the invisibility of the watermark and by other hand forms the third key. Let's be RY_{ij} the result of this insertion.
- Apply the inverse ROPT to each block RY_{ij} to obtain $Y_{ij}= ((P_N^{R})^{T}.\ RY_{ij}.\ P_N)/N$.
- Integrate the 8x8 Y_{ij} blocks to form the watermarked low-pass (LL_{Md}) sub-band.
- Apply the inverse transform IDWT to obtain the watermarked gray scale image.

B- Extraction algorithm

- Convert the original and the watermarked images into gray scale images if they are color ones.
- Apply the DWT to both images at the fixed level (d).
- Divide both low-pass sub-bands (LL_d) and (LL_{Md}), obtained by steep 2, into block B_{Oij} and B_{Mij} respectively of size 8x8.
- Use the first key to apply the ROPT to each block B_{Oij} and B_{Mij} : RB_{Oij}= ROPT $[B_{Oij}] = (P_N.\ B_{Oij}.\ (P_N^{R})^{T})/N$, and RB_{Mij}= ROPT $[B_{Mij}] = (P_N.\ B_{Mij}.\ (P_N^{R})^{T})/N$, N=8.
- The blocks of watermark are extracted by using RB_{Oij}, RB_{Mij} and the third key (λ). Let be RW_{Eij}
- By using the second key, apply to each block RW_{Eij} the inverse ROPT. Let be $W_{Eij}= ((P_N^{R})^{T}.\ RW_{Eij}.\ P_N)/N$.
- Integrate the 8x8 W_{Eij} blocks to form the extracted watermark.
- Check the similarity between the original watermark and the extracted one by using the normalized correlation given by (9). If the value of similarity is larger than a threshold, the watermark is successfully extracted, else the watermark does not exist or we fail to detect it.

$$NC = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M} W(i,j) * W_E(i,j)}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M} W^2(i,j) * \sum_{i=1}^{N}\sum_{j=1}^{M} W_E^2(i,j)}} \qquad (9)$$

V- EXPERIMENT RESULTS AND DISCUSSIONS.

In this section, we illustrate performance of the proposed method against some attacks such as JPEG compression, low pass filtering and noise adding. The proposed algorithm was simulated by using matlab software. A Lena image of size 512x512 and watermarks of size 256x256, 128x128, 64x64 were used as benchmark to test the performance of the algorithm.

Fig.2.c shows the watermarked image obtained by hiding the watermark shown by Fig.2.b within the original image of Fig.2.a. As it can be seen the watermark is imperceptible and the image quality is preserved. This is also checked by computing the PSNR (Peak Signal to Noise Ratio) between the original image and the watermarked one using (11). Fig.3 gives idea about PSNR values versus values of watermarking strength parameter (λ). This for each decomposition level (LL_d) used for inserting watermark.

$$MSE = \frac{1}{m.n}\sum_{i=1}^{m}\sum_{j=1}^{n}[I(i,j) - I^*(i,j)]^2 \qquad (10)$$

$$PSNR = 10\log\left(\frac{I^2_{\max}}{MSE}\right) = 20\log\left(\frac{I_{\max}}{\sqrt{MSE}}\right) \qquad (11)$$

MSE: mean square error.
I(i , j) : original image.
$I^*(i , j)$:watermarked image.
m , n : specify row and column of images size respectively.
I_{max} : maximal value of the pixel.

Figure 2-a Original image

Figure 2-b Original watermark

Figure 2-c watermarked image

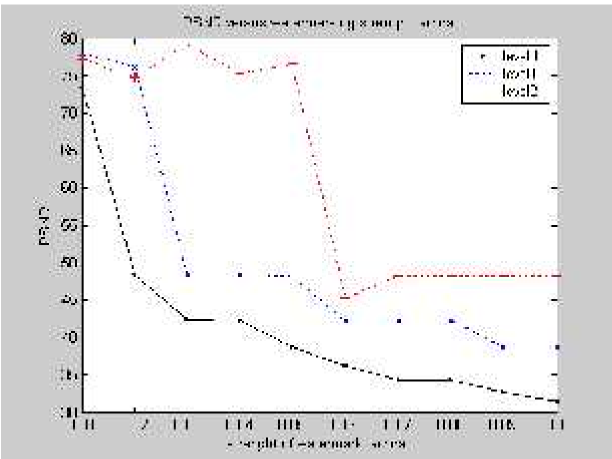


Figure 3 PSNR versus watermarking strength λ for level 0, 1 and 2

From Fig.3 and Fig.4 we can conclude that the PSNR obtained, for the three cases of inserting the watermark, is quite acceptable for all values of (λ) ranging from 0.01 to 0.1. Whereas the recovering of watermark is limited in the case of level 2 at values of 0.06 ≤ λ ≤0.1, it is sure in the case of level0 and level1 at values of 0.02 ≤ λ ≤0.1 and at values of 0.03 ≤ λ ≤0.1respectively. Hence, for the following tests (λ) is chosen between 0.06 and 0.1.

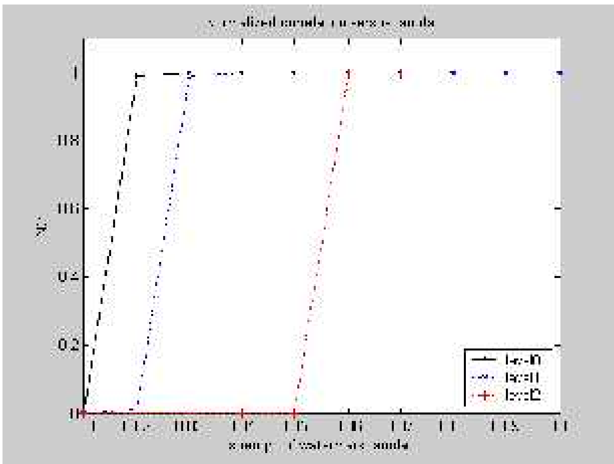


Figure 4 Normalized correlation versus watermarking strength λ for level 0, 1 and 2

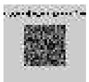
Original watermark of size 256x256 for level d=0

Extracted watermark of size 256x256 for level d=0

Original watermark of size 128x128 for level d=1

Extracted watermark of size 128x128 for level d=1

Original watermark of size 64x64 for level d=2



Extracted watermark of size 64x64 for level d=2

Figure 5 extracted watermarks for the three levels for Q=50 and λ=0.1

A- Test of the robustness against JPEG compression

In this kind of test the watermarked image is compressed by different quality factors. Results illustrated by Fig.5 show the extracted watermarks for Q=50, λ=0.1 according to the decomposition level (LL_d).

To check the similarity between the extracted watermark and the original one; the normalized correlation (*NC*) given by (9) was used. Results of Fig.6 show the trend of (*NC*) versus quality factors.

The quality of the extracted watermark is considered as good if the value of the (*NC*) is above then 50%. Hence, the results of Fig.5 and Fig.6 testify the robustness of the proposed method against JPEG compression. Indeed, the watermark can be extracted even for lower value of JPEC quality.

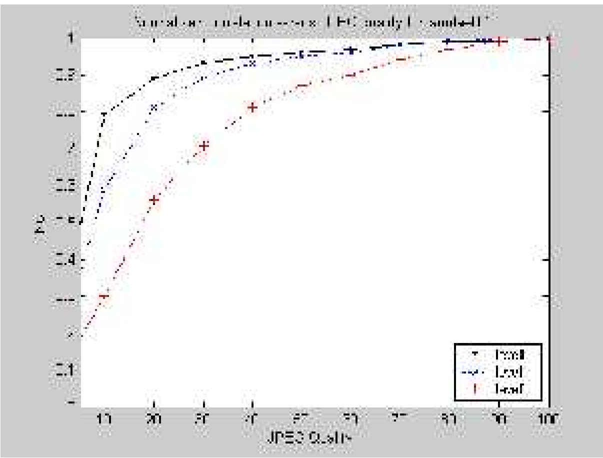


Figure 6 Normalized correlation versus JPEG quality for λ=0.1

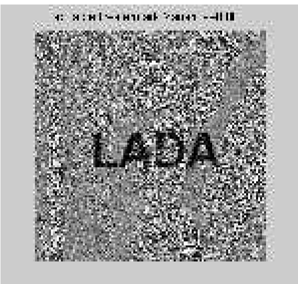
B- Test of the robustness against additive noise

In this experiment, the watermarked image is attacked by various noises such as Gaussian white noise, speckle& salt and pepper. Fig.7 illustrates the extracted watermark for a decomposition level d=0 and λ= 0.1.

The extracted watermark is compared with the original one by using the normalized correlation (*NC*). Plots of Fig.8, Fig.9 and Fig.10 give the variation of (*NC*) versus noise variance (V) according to the decomposition level used for inserting the watermark.

Original watermark

Gaussian white noise of V=0.0001



Speckle noise of V=0.001

Salt& pepper noise of density D=0.01

Figure 7 extracted watermark for Gaussian, speckle & slat and pepper noise

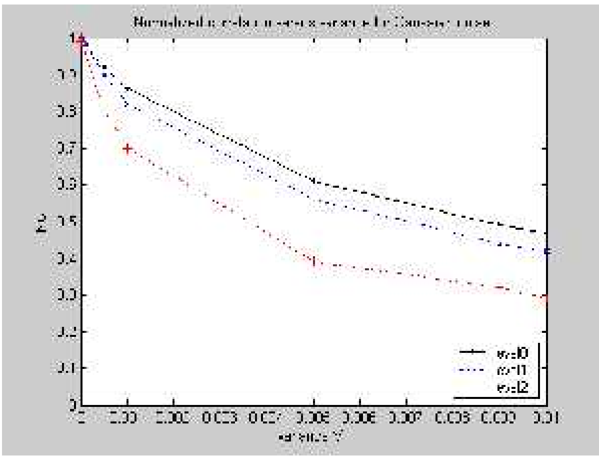


Figure 8 Normalized correlation versus Gaussian noise variance

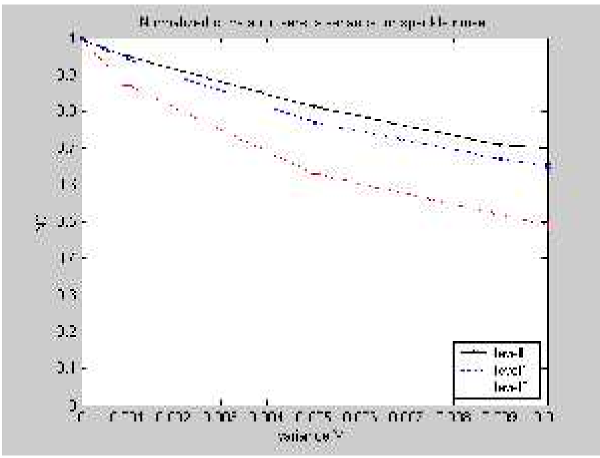


Figure 9 Normalized correlation versus speckle noise variance

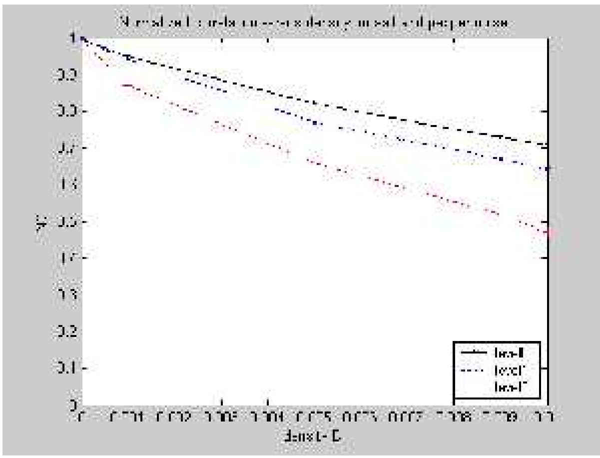


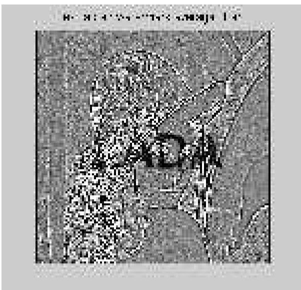
Figure 10 Normalized correlation versus salt & pepper noise density

C- Test of the robustness against low pass filtering

In this case of attacks the watermarked image is filtered by three kind of filter namely Gauss, average and disk. Fig.11 shows the extracted watermark for each type of filter of size 3x3in the case of level 0. As it can be seen, the watermark extracted in the case of the Gauss filter is better than others. This is due to its nature which is a rotationally symmetric Gaussian low pass filter unlike the others which are averaging filter and circular averaging filter respectively.

Fig.12 gives the trend of normalized correlation (*NC*) versus the standard deviation of the Gauss filter of size 5x5 for the three decomposition levels. Since the (*NC*) is above 0.5, almost for all the standard deviation values of the Gauss filter, then we can conclude that the proposed method is withstanding low pass filter attacks.

a. Gauss filter



b. Average filter

c. disk filter

Figure 11 extracted watermark in case of Gauss, average and disk filter of size 3x3

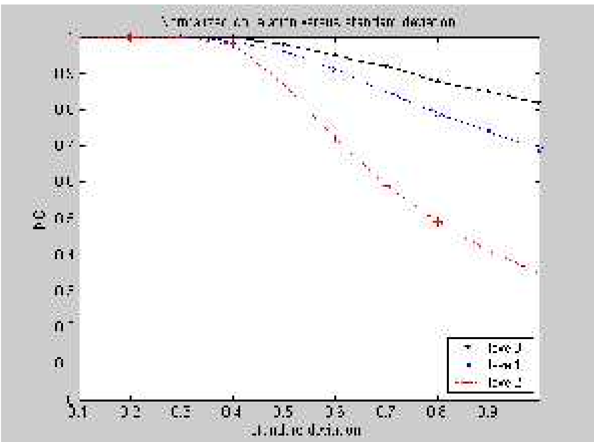


Figure 12 Normalized correlation versus standard deviation for Gauss filter of size 5x5

VI-CONCLUSION

In this paper we have proposed a hybrid watermarking method based on the use of multi-level DWT decomposition and a new class of reciprocal- orthogonal parametric transforms (ROPT). Our aim is to increase the watermarking method security, therefore increasing the robustness of the watermark against malicious attacks aiming for example its detection and removing or changing. For doing, a new method for generating key is used. We exploit the huge number of independent parameters (3N/2) provided by the ROPT as supplement watermarking key added to the one used for inserting the watermark. To get rid of the disadvantage of the ROPT which gives a non uniform partition of frequencies a multi-level DWT decomposition is used.

In addition to security, the proposed method is found to be robust against several attacks such as JPEG compression, low pass filtering, and added noise and even for combined attacks.

Finally, we will envisage improving the developed method by extending its robustness to other attacks particularly geometric transformations (RST).

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