Spread Spectrum Watermarking Using HVS Model and Wavelets in JPEG 2000 Compression

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Abstract— **This paper presents the improvement of watermarking images by the joint use of the technique of spread spectrum (robustness) and a psycho visual mask pattern (imperceptibility) in the JPEG 2000 compression. Previous work had shown the benefit of using the technique of spread spectrum in the safety of the JPEG 2000 compression.**

After the wavelet decomposition of the image, the brand is inserted in the high frequencies corresponding to the details. To make the tattoo more robust to detection during transmission, this is done by spreading the spectrum of the modulation mark consisting of the modulation of the signature by a pseudo random code generated using a private key.

To improve the imperceptibility of the watermark, mask psycho visual HVS weighting allows the insertion force tattoo on each frequency details of the wavelet transform. Psycho visual mask reflects the sensitivity of the human eye to noise, the local brightness and distortion around the edges.

Detecting the mark is made by comparison with a threshold, the correlation coefficients between the images during decompression details JPEG 2000.

The obtained results after application on Lena image are then analyzed and discussed in this paper.

Keywords— ***Watermarking, Spread Spectrum, JPEG 2000 compression, Multiresolution Analysis, HVS Model***

I. Introduction

This work is a contribution to the development of JPEG 2000, Part 8, in its dealing with security through the use of watermarking during compression. Tattooing is used here in the copyright protection of compressed images. The aim of this work is to integrate within the JPEG 2000 compression a robust structure that would allow the owner of an image to hide his signature proof of ownership. It is therefore to improve the work of Diop et al. [1] who used spread spectrum watermarking in JPEG 2000 compression.

In previous work, it can be noted:

- Davoine and Cayré [2] presented a diagram where the signature is encoded by means of private key using orthogonal functions. It also uses the Human Visual System HVS mask of Barni et al. [3].
- Woo [4] presented a schema which improved the HVS mask of Barni [4] and reduced the calculation complexity of the HVS mask of Davoine.

In LIMBI laboratory, Diop et al. [1][5] used a spread spectrum watermarking diagram within JPEG 2000 compression.
Now the purpose of this paper is to improve Diop work by joining HVS mask to spread spectrum watermarking.

II. The Watermarking Scheme

When performing the compression operation, the watermark is inserted during the wavelet transform stage. The use of JPEG 2000 compression standard which integrates wavelet decomposition will therefore gain in computation time compared to other compression types (figure 1).

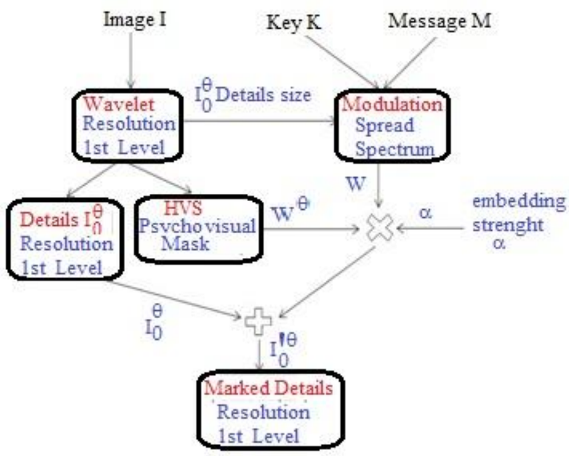

Figure 1: Watermarking scheme

A. Discrete Wavelet Transform DWT

Wavelets properties have good applications in image processing. Like the human visual system, the wavelet decomposition filters the image and separates the high frequencies (images details) from low frequencies (approximated images). Human eye is more sensitive to the noise located in the low pass frequencies.

On the one hand, wavelet transform is a step of JPEG 2000 compression. The watermark is inserted in the detail sub-bands in the first resolution level of the wavelet decomposition (fig. 2).

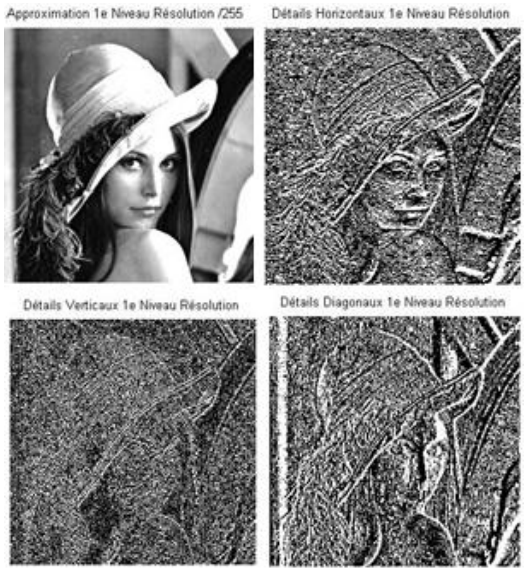

Figure 2 : First resolution level wavelet decomposition

On the other hand, wavelet decomposition is used to the 4th resolution level in the computation of the HVS psycho visual mask as shown in the Mallat diagram of fig. 3.

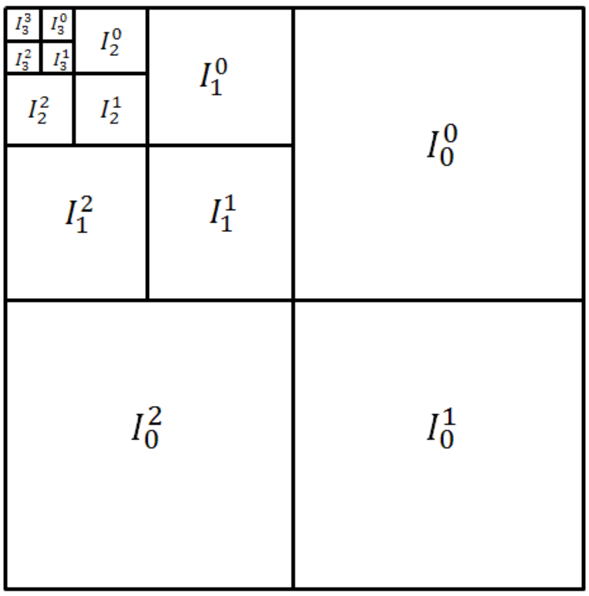

Figure 3 : 4 resolution levels of wavelet decomposition Modelling Watermarking as a transmission analogy

Here watermarking is modeled as a transmission problem as indicated in [5]. The wavelet transformed image is viewed as a transmission channel. It breaks down into frequencies as a communication channel does. It consists of low frequencies and high frequencies. Like a communication channel, a watermarked image is a medium and data can be transmitted through it. The image seen as a channel provides an approximated sub-band (in low band) and three high sub-bands resulting from high pass wavelet decomposition. The signature is the information to send through the channel. It is first modulated by a ***pseudo-random code*** as a carrier. The used technique for the modulation is spread spectrum.

In the transmission field [6], a ***spread spectrum*** system is when the band of the spectrum that is filled in the transmission channel is far larger than the minimal band sufficient to transmit data. The spread spectrum technique is an old idea. The principle is to scatter the energy of signals on a large range of the frequency spectrum in the channel. The operation has, as a consequence; to reduce the power spectral density. This means that a weak portion of signals is transmitted through a piece of frequency in a given time. The reception consists of the compression of the large spectrum received. In general in the spreading process, a pseudo-random signal is multiplied by the signal designed to be spread.

In this spread spectrum watermarking context a pseudo-random binary code is generated with a private key K. It constitutes the carrier that modulates the signature M to produce the watermark W.

B. Watermarking equation and its components

As shown in fig. 1, equation (1) makes the insertion mark in the details of the wavelet transform.

$$I_0'^{\theta}(i,j) = I_0^{\theta}(i,j) + \alpha \times w^{\theta}(i,j) \times \left|I_0^{\theta}(i,j)\right| \times \mathrm{W}(i,j) \quad (1)$$

$\theta \in \{0,1,2\}$ is the selected high pass sub-band
$I_0^{\theta}(i,j)$ are the original sub-bands coefficients
$I_0'^{\theta}(i,j)$ are the watermarked sub-bands corresponding to $I_0^{\theta}(i,j)$ image sub-band

α is the global energy parameter that determines the watermarking strength.

w^{θ} is a weighting function derived from local sensitivity to noise that gives HVS model masking characteristics.

W is the watermark; the modulated signature by a pseudo-random code generated by computation with orthogonal functions.

III. MODULATION OF THE SIGNATURE

Taking K the private key that generates the Pseudo-Random Binary Matrix (PRBM), and M the signature, the following conditions must be verified by M and K.

$$M = \bigoplus_{i=1}^{w} \mathrm{M}_i^r \,,\ \mathrm{M}_i^r \in \{0;1\}^r, \qquad \forall i \in [1;w] \quad (2)$$

$$K = \bigoplus_{i=1}^{w} \mathrm{K}_i^l \,,\ \mathrm{K}_i^l \in \{0;1\}^l, \qquad \forall i \in [1;w] \quad (3)$$

$$\text{And } \forall\,(i,j) \in [1;w]^2 \qquad \mathrm{K}_i^l \neq \mathrm{K}_j^l \quad (4)$$

$\bigoplus$ is the concatenation operator.

The signature is divided into w packets of r bits and the key is also divided to w packets of l bits. The key packets must be different to be sure that there will not be interferences. We consider an image l of 2m X 2n dimensioned and 2 sets of basic functions $F_{M,k}$ and $F_{K,k}$.

$$F_{M,k}: [0;m] \times [0;n] \rightarrow \mathbb{R}, k \in \mathbb{N}$$

$$F_{K,k}: [0;m] \times [0;n] \rightarrow \mathbb{R}, k \in \mathbb{N}$$

Arbitrarily r = l. $k \in [1, 2^r]$ for $F_{M,k}$ and $k \in [1, 2^l]$ for $F_{K,k}$.

These functions verify the following intra-orthogonality and inter- orthogonality constraints:

$$\forall (\alpha, \beta) \in \mathbb{N}^2 \langle F_{M,\alpha}, F_{M,\beta} \rangle = \delta_{\alpha,\beta} \quad (5)$$

$$\forall (\alpha, \beta) \in \mathbb{N}^2 \langle F_{K,\alpha}, F_{K,\beta} \rangle = \delta_{\alpha,\beta} \quad (6)$$

$$\text{and } \forall (\alpha, \beta) \in \mathbb{N}^2 \langle F_{M,\alpha}, F_{K,\beta} \rangle = 0 \quad (7)$$

Every binary packet is viewed as an index as followed: the M_i^r packet of the signature indexes one of the 2^r functions $F_{M,k}$, the K_i^l packet of the key indexes one of the 2^l functions $F_{K,k}$. Consider $b_v: \{0,1\}^v \rightarrow \mathbb{N}$, a bijection that make it possible to associate a value to a binary segment. The following equation defines the watermarking function W that produces the modulation of the signature. The look is given in Figure 4.

$$W = \dots \frac{1}{w} \times \begin{pmatrix} F_K(1,1) & \cdots & F_K(1,w) \\ \vdots & \ddots & \vdots \\ F_K(M,1) & \cdots & F_K(M,w) \end{pmatrix} \times \dots \begin{pmatrix} F_M(1,1) & \cdots & F_M(1,N) \\ \vdots & \ddots & \vdots \\ F_M(w,1) & \cdots & F_M(w,N) \end{pmatrix} \quad (8)$$

Where M and N are the size of the high sub-bands I_0^θ

$$F_K(i,p) = F_{K,b_l(K_p^l)}(i,j) = \cos\left(\frac{2 \times \pi \times b_l(K_p^l) \times i}{\beta_K}\right)$$

$$F_M(p,i) = F_{M,b_r(M_p^r)}(i,j) = cos\left(\frac{2 \times \pi \times b_r(M_p^r) \times i}{\beta_M}\right)$$

Figure 4 : The watermark W of M × N sized

IV. THE HVS PSYCHOVISUAL MASK

It introduced an embedding weight factor that exploited Human Visual System characteristics. It adapted:

- the embedding strength α according to the variations of the edges and textures,
- and noise sensitivity to local luminosity.

The method thus gained in robustness and imperceptibility.

Originally this mask was implemented by Levis and Knowles to develop a mask psycho visual quantization steps. In particular, they assumed:

Eyes are less sensitive to noise in high resolution bands and bands with an orientation of 45°.

Eyes are less sensitive to in areas of most textured images.

Subsequently, Barni et al. and after Davoine and Cayré used this HVS mask in watermarking. The HVS psycho visual mask of Barni et al. had been worked up by Woo et al. to produce a simplified mask with reduced computational cost. Here is a presentation of the different elements that compose the mask as Barni et al. did.

$$q_l^\theta = \Theta(l,\theta) \times \Lambda(l,i,j) \times \Xi(l,i,j) \quad (9)$$

Where

$* \ \Theta(l,\theta)$ *is the noise sensitivity*

$$\Theta(l,\theta) = \begin{Bmatrix} \sqrt{2} & if \ \ \theta=1 \\ 1 & \text{other} \end{Bmatrix} \cdot \begin{cases} 1.00 & si \ l=0 \\ 0.32 & si \ l=1 \\ 0.16 & si \ l=2 \\ 0.10 & si \ l=3 \end{cases} \quad (10)$$

i.e

$$\Theta = \begin{bmatrix} 1.0000 & 1.4142 & 1.0000 \\ 0.3200 & 0.4525 & 0.3200 \\ 0.1600 & 0.2263 & 0.1600 \\ 0.1000 & 0.1414 & 0.1000 \end{bmatrix} \quad (10)$$

This term took account of how the sensitivity to noise changed according to the considered sub-band (particularly according to the orientation and the image detail level) [3].

$* \ \Lambda(l,i,j)$*is the local luminosity*

$$\Lambda(l,i,j) = 1 + L(l,i,j) \quad (11)$$

$* \ K(l,i,j)$*is the local brigthness*

$$K(l,i,j) = \frac{1}{256} \times I_3^3 \left(1 + \left[\frac{i}{2^{3-l}}\right], 1 + \left[\frac{j}{2^{3-l}}\right]\right) \quad (12)$$

$$L(l,i,j) = \begin{Bmatrix} 1-K(l,i,j) & if \ \ K(l,i,j)<0.5 \\ K(l,i,j) & others \end{Bmatrix}$$

Only the value of Λ corresponding to l = 0 is used in the computation of q_l^θ (q_0^θ) because the details of the 1st resolution level are used to embed the watermark. Then the computation for other values of l (l = 1 ... 3) are vain. So Λ is the result of an ***up-sampling*** operation (at the third level, see fig. 5 and fig. 6) of the 4th resolution level approximation I_3^3 that is indicated in the Mallat Diagram (fig. 1).

** Edges, Distance and textures [2]*

$$\Xi(l,i,j) = \sum_{k=0}^{3-l} \frac{1}{16^k} \sum_{\theta=0}^{2} \sum_{x=0}^{1} \sum_{y=0}^{1} \left[I_{k+l}^{\theta} \left(y + \frac{i}{2^k}, x + \frac{j}{2^k} \right) \right]^2 \ldots$$

$$\ldots \times \operatorname{var}\left\{ I_3^3 \left(1 + y + \frac{i}{2^{3-l}}, 1 + x + \frac{j}{2^{3-l}} \right) \right\}_{\substack{x=0,1 \\ y=0,1}} \quad (13)$$

This term gives a measurement of the activity of texture in the neighborhood of the pixel. In particular, this term consists by two contributions: the first is the local mean square value of the local mean square value of the DWT coefficients in all detail sub bands at the coarser levels (see the Mallat Diagram, fig. 3), while the second is the local variance of the low sub-band, both these contributions are computed in a small 2X2 neighborhood corresponding to the pixel location (i, j) [3].

Considering that variations lower than ½ of computed weights are imperceptible, the weighting function w^{θ} gives maximum insertion energy in the quantization of DWT coefficients using

$$w^{\theta}(i,j) = \frac{q_0^{\theta}(i,j)}{2} \quad (14)$$

Figure. 5 : K coefficients to compute local luminosity

I. SIGNATURE READING

The reading of w packets of r bits through the watermarked image $I_0'^{\theta}$ can be performed easily as mentioned in Davoine paper [2], if orthogonality conditions (5), (6) and (7) are verified. The following easy method is proposed here. Considering a given key K and a watermarked image I:

The key K is broken down according to (3) to extract the K_p^l. Now we compute the correlations between the $I_0'^{\theta}$ and the products $w^{\theta} \times F_{K,b_l(K_p^l)}(i,j) \times F_{M,b_r(M_q^r)}(i,j)$ for every $q \in \{1, 2^r\}$. The mask w^{θ} is computed on the watermarked and possibly attacked image. For a given K_p^l packet, we keep only the function $F_{M,b_r}(M_q^r)$ that gives the maximum correlation $C_{1\,F_M}^{\max}(K_p^l)$ of 2^r. The $F_{M,b_r}(M_q^r)$ function associated with the K_p^l packet is judged good if the difference between the two first maximum correlations is higher than a fixed threshold according to the following:

$$C_1 - C_2 > \tau \times C_1, \quad \text{with } 0 < \tau < 0.3 \quad (15)$$

C2 is the maximum correlation less than C1.

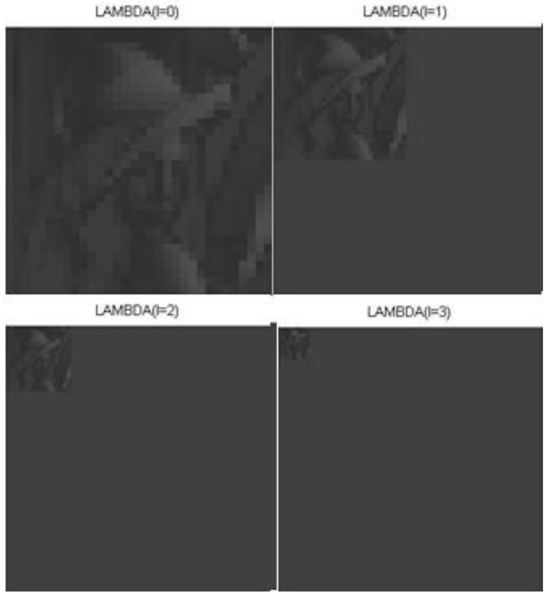

Figure 6 : the Local Luminosity

If the test (15) was successful, the binary sequence M_q^r that constituted a part of the signature M would be found by the reverse binary to character transform b_r^{-1}.

II. RESULTS

The watermarked scheme was simulated with Matlab.

To determine the influence of some parameters on the watermarked image, PSNR between original and watermarked images was calculated.

The first parameter to study its influence is the size of the mark (8 and 16 packets of message and key). The second is the insertion force coefficient α.

Comparing those images, we find that watermarked image (fig. 7) is quite similar to the original (fig. 8).

Figure. 7 : The watermarked image

Figure 8 : the original image

This visual observation is confirmed by the measurement of PSNR (fig. 9).

Varying also the insertion force α, the PSNR parametric curves are determined; changing the size of the message and the key (8 packets and 16 packets) are also done by simulation.

In this case, curves (8 and 16 bits) give the same value of PSNR when insertion force α varies (fig. 8). It can be noted that when the insertion force a increases, the PSNR decreases.

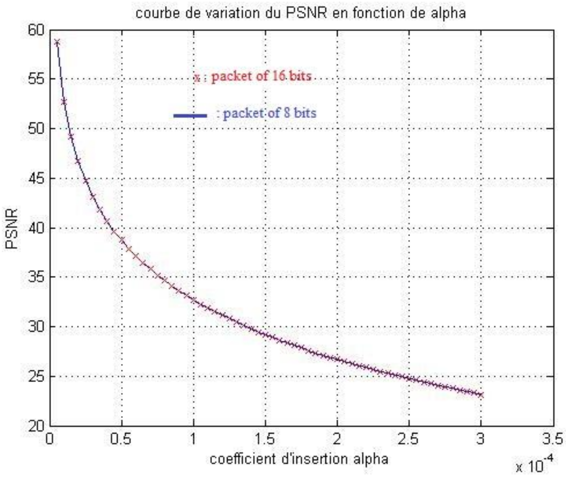

Figure 9 : curves of PSNR versus insertion force for packet of 8 and 16 bits

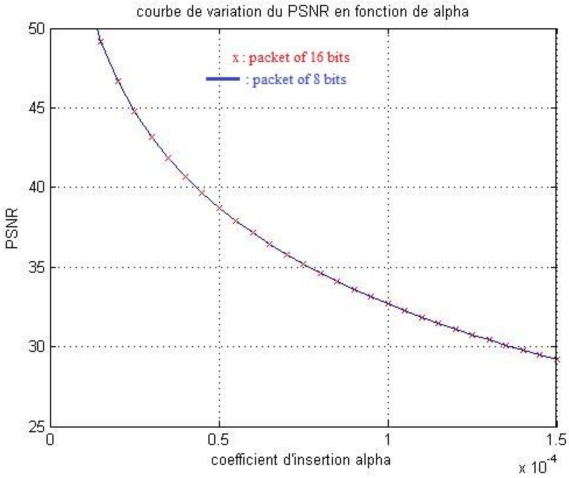

Figure 10 : curves of PSNR versus insertion force less than 0.00015 for packet of 8 and 16 bits

The value of PSNR is good, more than 30 dB for insertion force α less than 0.00015.

These results denote that the model is appropriate to achieve the aim.

The work may be continued in the part of reading the message embedded and testing the robustness and the imperceptibility during attack by JPEG 2000 compression.

III. Conclusion

The work presented in this paper shows convincing results in the imperceptibility of the mark inserted during watermarking spread spectrum. It was first shown the necessary theoretical tools for modeling (decomposition into sub-bands of images, the modulation information inserted by orthogonal functions, etc.) And then gave the watermarking scheme.

The measurement of PSNR between the watermarked image and the original has given good results to validate the model.

The work should be completed later by performing a transmission through a noisy channel and after compression by JPEG 2000 and reading the mark at the reception.

IV. References

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