EFFICIENT INFORMED EMBEDDING OF MULTI-BIT WATERMARK

Joceli Mayer and Rafael Araujo Silva

Digital Signal Processing Research Laboratory
Department of Electrical Engineering
Federal University of Santa Catarina
Florianpolis -SC, Brazil 88040-900
e-mails: {rafael.araujo, mayer}@eel.ufsc.br

ABSTRACT

In this paper we present a practical blind detection system for multi-bit watermarking. Differently from [1], we propose a deterministic embedding scheme that does not depend on statistical assumptions about the original image. The proposed system can be considered an extension of [2] for multi-bit messages using code division multiplexing. By informed embedding, using the knowledge of the original image and the detection scheme, the proposed system assures total embedding efficiency. We analyze the impact of valumetric distortion sources on the ability to recover the watermark message and propose a simple parameter to control system robustness. Experimental results obtained for spatial domain watermarking illustrate the efficiency of the proposed system.

1. INTRODUCTION

Among many existing approaches, spread spectrum is frequently used in watermarking systems. In spread spectrum (SS) watermarking, a bit of information is spread over many samples of the host content by the use of reference patterns obtained from generators of pseudo-random sequences. The proposed system is based on the ideas of the following reference papers which are based on SS techniques. In [1], the problem of performance analysis of a image watermarking system that does not require the availability of the original image at detector is addressed. A theoretical statistical approach was derived to obtain models that provide a basis for the application of decision theory to the design of efficient detector structures. *Cox et al* in [3] stated that a watermark embedder can be made more effective if it is designed exploiting host content information together with the knowledge of the watermark detection scheme. In [2], a simple one-bit image watermarking system applying the ideas of informed embedding presented in [3] was proposed to compare its performance against a blind embedding scheme. In this paper, we propose a watermarking technique which allows us to encode a message of multiple bits into a digital image. In short, this watermarking system can be considered as an efficient extension of [2] for multi-bit watermarking using code-division multiplexing. Unlike the statistical approach of [1], the proposed system has a deterministic watermark embedding scheme that assures total embedding efficiency. In Section 2 we provide the mathematical formulation of the proposed system considering watermark embedding, detection and the impact of valumetric distortion sources on the ability of message recovery. In Section 3 we show some experimental results using the proposed watermarking system in the spatial image domain.

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2. PROPOSED SYSTEM

Consider $\bar{C_O}$ a vector of length M containing the elements of the host image. We want to embed into $\bar{C_O}$ a multi-bit message $\bar{B}$ of length N.

$$\bar{B} = [B_1, B_2, \ldots, B_N], B_j \in \{-1, +1\} \tag{1}$$

To obtain the watermark vector $\bar{W}$ of length M carrying the N-bit message, we construct a set $\mathcal{P}$ of N reference marks. Each reference mark $\bar{P}_j$ is a pseudo-random sequence of length M.

$$\mathcal{P} = \{\bar{P}_1, \bar{P}_2, \ldots, \bar{P}_N\} \tag{2}$$

$$\bar{P}_j = [P_{j1}, P_{j2}, \ldots, P_{jM}], P_{ji} \in \{-1, +1\} \tag{3}$$

The pseudo-random sequence elements P_{ji} are random numbers assuming -1 or $+1$ according to a uniform, zero-mean, probability density function. For code division multiplexing, the pseudo-random sequences of the set $\mathcal{P}$ should be orthogonal to each other. We use *rand()* available in ANSI C library and MATLAB functions to obtain the reference marks. The initial state of the random sequence generator defines the cryptographic key K of the watermarking system. This key K should be known by both embedder and detector such that they generate the same set $\mathcal{P}$. The reference marks resulting from the use of *rand()* are not strictly orthogonal [4]. This observation is important for watermarking systems whose reference marks length M are short. Non-orthogonality between reference marks results in a sort of intersymbolic interference that may compromise the embedding efficiency of the system. In the following equations we will show how to achieve total embedding efficiency. By equation (4) we spread the N-bit message $\bar{B}$ into an M-dimensional sequence W corresponding to the watermark vector. The gain factor α determines the watermark magnitude.

$$\bar{W} = \alpha \cdot \sum_{j=1}^{N} B_j \cdot \bar{P}_j \tag{4}$$

In a blind embedding scheme, we obtain the watermarked image vector by $\bar{C_W} = \bar{C_O} + \bar{W}$. Blind embedding schemes do not assure embedding efficiency and also do not explore properties of the HVS to improve the perceptual transparency. To introduce perceptual modeling improving watermark transparency, we propose the use of a multiplicative mask $\bar{Msk}$ according to (5).

$$\bar{C_W} = \bar{C_O} + \bar{Msk} * \bar{W} \tag{5}$$

The operation * is defined for the element-by-element multiplication of the vectors. Vector $\bar{Msk}$ is a masking image with elements ranging from 0 to msk_{max} according to the insensitivity of the perceptual impact of the watermark added to the original image. Reference [5] proposes a method to obtain an spatial domain perceptual mask. In Fig. 1 we show the proposed mask for watermark embedding. The mask is obtained by the squared root of the absolute value of the elements of the Inverse Discrete Wavelet Transform (IDWT) image reconstruction considering only the detail sub-bands (HL1, LH1 and HH1). Note that regions of edges and texture will receive more watermark energy. To assure total embedding efficiency, we need to propose an embedding scheme that compensates the non-orthogonalities between host image and reference pattern vectors. Considering the use of linear correlation for message recovery at watermark detector, we show how these non-orthogonalities between vectors appear as interference components in the

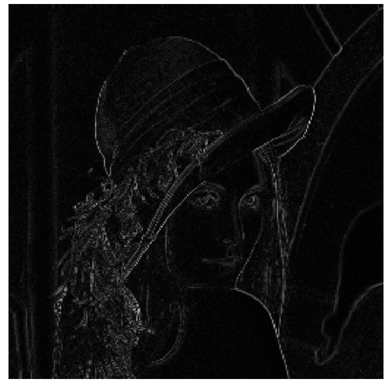


Fig. 1. Example of a wavelet-based mask for watermark embedding.

decision variable D_k of equation (6).

$$\begin{aligned} D_k &= \langle \bar{C_W}, \bar{P}_k \rangle = \frac{1}{M} \sum_{i=1}^{M} C_{Wi} \cdot P_{ki} \\ &= \left\langle \bar{P}_k, \left[\bar{C_O} + \alpha \cdot \sum_{j=1}^{N} B_j \cdot \bar{Msk} * \bar{P}_j \right] \right\rangle \\ &= \langle \bar{P}_k, \bar{C_O} \rangle + \alpha \cdot B_k \cdot \langle \bar{P}_k, \bar{Msk} * \bar{P}_k \rangle \\ &\quad + \alpha \cdot \sum_{j=1, j \neq k}^{N} B_j \cdot \langle \bar{P}_k, \bar{Msk} * \bar{P}_j \rangle \end{aligned} \tag{6}$$

For the N-bit message recovery at detector, we have to evaluate D_k and take a binary decision for $k = 1, 2, \ldots, N$. If $D_k > 0$, $B_k = +1$, otherwise $B_k = -1$. Since $P_{ki} \in \{-1, +1\}$, we know that $\langle \bar{P}_k, \bar{Msk} * \bar{P}_k \rangle = \frac{1}{M} \sum_{i=1}^{M} Msk_i \cdot P_{ki}^2 = \mu_{\bar{Msk}}$. For simplification, if we call $R_k^{(\bar{C_O})} = \langle \bar{P}_k, \bar{C_O} \rangle$ and $R_k^{(\bar{Msk} * \bar{P}_j)} = \alpha \cdot \sum_{j=1, j \neq k}^{N} B_j \cdot \langle \bar{P}_k, \bar{Msk} * \bar{P}_j \rangle$, then equation (6) results in

$$D_k = \alpha \cdot B_k \cdot \mu_{\bar{Msk}} + (R_k^{(\bar{C_O})} + R_k^{(\bar{Msk} * \bar{P}_j)}) \tag{7}$$

Unfortunately, $R_k^{(\bar{C_O})} = 0$ and $R_k^{(\bar{Msk} * \bar{P}_j)} = 0$ cannot be assumed. These residual components from non-orthogonalities may cause bit errors. To assure the system embedding efficiency, we need to compensate the harmful interference of these residual components in the decision variable D_k setting an appropriate α value. As we have different residual components for each decision variable D_k, we make the following change in the step of watermark construction (8) to allow the appropriate setting of individual gain factors α_j for each reference mark.

$$\bar{W}^* = \sum_{j=1}^{N} \alpha_j \cdot B_j \cdot \bar{P}_j \tag{8}$$

Solving the following system of linear equations we obtain the values of α_j that assure embedding efficiency,

$$\begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1N} \\ A_{21} & A_{22} & & \vdots \\ \vdots & & \ddots & \\ A_{N1} & \cdots & & A_{NN} \end{bmatrix} \cdot \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_N \end{bmatrix} = \begin{bmatrix} \beta \cdot B_1 - R_1^{(\bar{C_O})} \\ \beta \cdot B_2 - R_2^{(\bar{C_O})} \\ \vdots \\ \beta \cdot B_N - R_N^{(\bar{C_O})} \end{bmatrix} \tag{9}$$

where $A_{ij} = B_j \cdot \langle \bar{P_i}, \bar{Msk} * \bar{P_j} \rangle$ and β is the value that we want to attribute to the decision variable D_k. In other words, we want to set $D_k = \beta \cdot B_k$ for $k = 1, 2, \cdots, N$. The importance of β will become clear in the following discussion about watermark robustness against valumetric distortion sources such as operations of image enhancement and lossy compression. Generalizing the existence of valumetric distortion sources in the watermarked image path, we define a distortion vector $\bar{n}$ that changes the elements of the watermarked image vector $\bar{C_W}$ according to (10).

$$\bar{C_W}' = \bar{C_W} + \bar{n} \tag{10}$$

As vector $\bar{n}$ is unknown at the time of watermark embedding, it is not possible to compensate its interference in the decision variable D_k as we did for the residual components $R_k^{(\bar{C_O})}$ and $R_k^{(\bar{Msk} * \bar{P_j})}$. Thus, the computation of the linear correlation for each message bit becomes

$$D_k = \beta \cdot B_k + R_k^{(\bar{n})} \tag{11}$$

where $R_k^{(\bar{n})} = \langle \bar{P_k}, \bar{n} \rangle$ is a random variable. Then, the choice of β in the watermark embedding scheme determines the robustness of the system against valumetric distortion sources.

Finally, performing the watermark construction and embedding steps according to equations (8) and (5) we obtain the proposed multi-bit watermarking system (12) that assures total embedding efficiency.

$$\bar{C_W} = \bar{C_O} + \bar{Msk} * \bar{W}^* \tag{12}$$

3. EXPERIMENTS

Most of watermarking applications require multi-bit message sizes of at least 64 or 70 bits [6]. To show some results we embed a 70-bit watermark message in the spatial domain of the Lena image using the proposed wavelet-based mask. Fig. 2(a) shows the watermarked image with $\beta = 0.5$ and Fig. 2(b) shows the distortion introduced by the watermark scaled for visibility.

Fig. 3 shows respectively the 70-bit watermark binary message, the values of the residual components $R_k^{(\bar{C_O})}$ and $R_k^{(\bar{Msk} * \bar{P_j})}$ for each bit decision variable, the appropriate

(a) (b)

Fig. 2. (a) Watermarked image with $\beta = 0.5$ and (b) difference $\bar{C_W} - \bar{C_O}$ scaled 10 times for visibility.

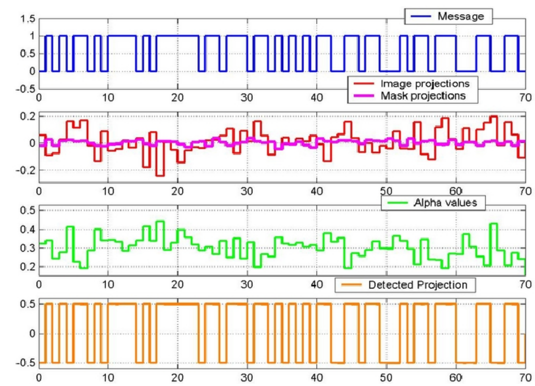
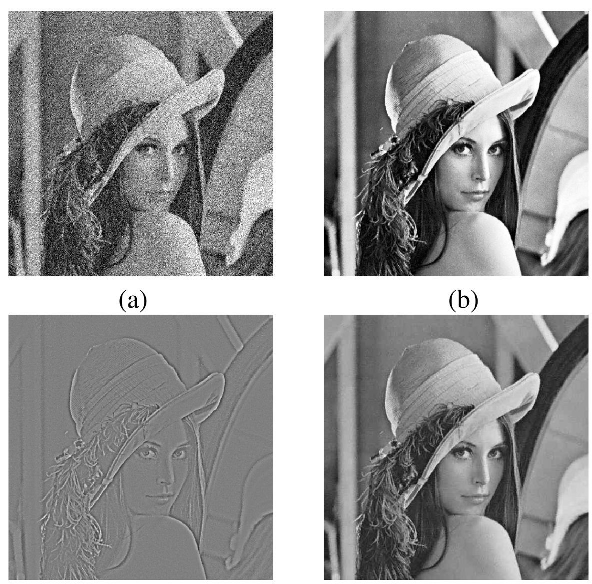


Fig. 3. Watermark message, Residual components, α_j values and linear correlation D_k for $\beta = 0.5$.



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

Fig. 4. Distorted watermarked images: (a) AWGN 20%; (b) Histogram Equalization; (c) High-pass filtering; (d) JPEG lossy compression quality factor 50.

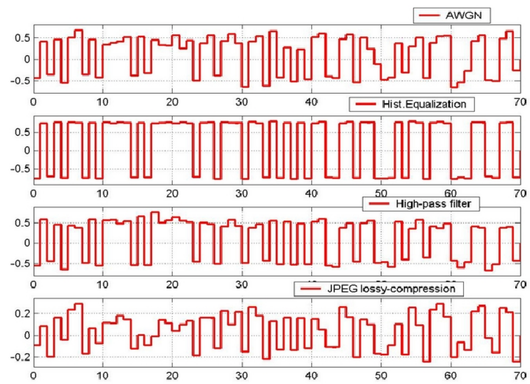


Fig. 5. Influence of the distortion sources on the linear correlation D_k.

values of α_j to assure embedding efficiency and the linear correlation results D_k. Observe that total embedding efficiency ($BER = 0\%$) is achieved. The small deviations observed in D_k around $\beta \cdot B_k$ value occur due to round-off and clipping effects. To test robustness against valumetric distortion sources we chose the following set of common image operations: AWGN (20%), histogram equalization, linear filtering (high-pass) and lossy compression (JPEG with quality factor = 50).

Fig. 4 shows the distorted watermarked images and Fig. 5 shows the interference of $R_k^{(\bar{n})}$ on the decision variable D_k for $\beta = 0.5$. However, no bit errors occurred for the set of distortion sources considered. The control of the decision variable D_k through β defines the watermark robustness against valumetric distortions. Estimating the amount of distortion sources in the watermarked image path, we can set β to embed a watermark energy just sufficient to overcome the estimated distortion interference $R_k^{(\bar{n})}$. Otherwise, if we have no distortion sources in watermarked image path, we can set β value as close as possible to the decision threshold improving watermark transparency with still total embedding efficiency. Table 1 presents the widely used measures of perceptual impact for two different β values used to embed the 70-bit watermark message shown in Fig.3.

Table 1. Perceptual impact measures for the watermarked images.

Watermark Fidelity		
Measure	$\beta = 0.05$	$\beta = 0.5$
MSE	1.19	25.57
SNR(dB)	41.68	28.37
PSNR(dB)	47.02	33.71

4. CONCLUSIONS

Observing the experimental results we can state that the proposed system can be used for semi-fragile watermarking applications. Once that the decision variable can be precisely set during watermark embedding, we would be able to detect considerable image changes observing the deviations of D_k values around $\beta \cdot B_k$.

5. REFERENCES

[1] J. R. Hernandez, F. Perez-Gonzalez, "Statistical analisys of watermarking schemes for copyright protection of images," in *Procedings of the IEEE*, 1999, vol. 87:7, pp. 1142 –1165.

[2] I. J. Cox, M. L. Miller, A. L. Mckellips, "Informed embedding: Exploiting image and detector information during watermark insertion," *in IEEE International Conference on Image Processing*, vol. 3, pp. 1–4, 2000.

[3] I.J. Cox, M.L. Miller, A.L. Mckellips, "Watermarking as communications with side information," *Proceedings of the IEEE*, vol. 87, no. 7, pp. 1127–1141, 1999.

[4] J. Mayer, A. V. Silverio, J. C. M. Bermudez, "On the design of pattern sequences for spread spectrum image watermarking," *Int. Telecommunications Symposium (ITS2002)*, 2002.

[5] M. Barni, F. Bartolini, A. Piva, "Improved wavelet-based watermarking through pixel-wise masking," *IEEE Transactions on Image Processing*, vol. 10, no. 5, pp. 783–791, 2001.

[6] SACD, INA, PHILIPS, TUD, TCC, NETIMAGE, UVIGO, "Watermarking applications and requirements for benchmarking," 1999.