Wavelet Domain Watermark Embedding Strategy using TTCQ Quantization

Azza Ouled Zaid†, Achraf Makhloufi†, Ammar Bouallegue†

†SYSCOM Laboratory, National Engineering School of Tunis, B.P. 37 le Belvédère 1002 Tunis, Tunisia

Summary

Invisible Digital watermarks have been proposed as a method for discouraging illicit copying and distribution of copyright material. Due to its characteristics, one of the problems in image watermarking is to decide how to hide in an image as many bits of information as possible while ensuring that the information can be correctly retrieved at the detecting stage, even after various attacks. Several approaches based on Discrete Wavelet Transform (DWT) have been proposed to address the problem of image watermarking. The advantage of DWT relative to the DCT is that it allows for localized watermarking of the image. The central contribution of this paper is to develop a watermarking algorithm, resilient to like lossy compression attack, by exploring the use of turbo trellis-coded quantization techniques (turbo TCQ) on the wavelet domain. Our results indicate that the proposed approach performs well against lossy wavelet-based compression attacks such as JPEG2000 and SPIHT.

Key words:

Wavelet transform, watermark embedding, TTCQ quantization, Image compression

1. Introduction

Digital watermarking consists in embedding an invisible message within a host signal. Most algorithms are either based on additive embedding or substitution by a codebook element. In Direct Sequence (DS) Spread Spectrum watermarking [1], the additive mark is the secret message modulated by a pseudo-noise. Insertion can be performed either in the spatial domain (luminance) or in invertible transform domains such as the Discrete Fourier Transform DFT, the Discrete Cosine Transform DCT or the Discrete Wavelet Transform DWT [2]. Since images may be severely distorted due to compression or manipulation, channel coding techniques are usually used in conjunction with data hiding methods, to remove the signal as source of interference. This realization has led to the design of algorithms for informed coding and informed embedding. In informed coding, a watermark is represented with a codeword that is dependent on the cover Work. In informed embedding, each watermark pattern is tailored according to the cover Work, attempting to attain an optimal trade-off between estimates of perceptual fidelity and robustness. Informed watermarking provides better performance by using knowledge upon both the host image and the detection technique at the embedding [3] [4].

Recent advances focus on random binning inspired from Costa's work in information theory [5]. The inserted mark is selected in a random codebook divided into bins. Each bin is associated to a possible secret message. For a given secret message, the inserted mark is the element of the adequate bin which is closest to the host data. In practice, a reasonably codebook can be constructed using quantization techniques (mainly scalar quantization): quantization index modulation (QIM) and scalar Costa scheme (SCS) [6]. Experiments have shown that SCS poorly performs for uncoded messages. Then, it must be associated to an efficient channel code, which reduces the embedding payloads. Moreover, several recent algorithms revisit spread spectrum techniques in the framework of informed embedding [7]. Recently, Miller et al. [8] proposed an informed coding and embedding approach, which optimally embed a watermark by applying modified TCQ in the DCT domain. The watermark robustness against JPEG compression attacks significantly out-performs these of blind coding methods.

In our work, in order to take advantage of wavelet space-frequency localization in the watermarking scheme, we propose an alternate approach where we derive a TTCQ strategy for embedding a watermark in the wavelet domain. This framework can be used on conjunction with wavelet based source coding such us JPEG2000, SPIHT or EZW.

We begin in section 2 by presenting the TTCQ method we adopt in the rest of the paper. In section 3 the embedding algorithm is described. In section 4 we present our results followed by the conclusion in section 5.

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2. A brief description of watermark embedding

As shown in Fig. 1, the watermark embedding can be formulated in a three-step process. First, the message **m** to be embedded is encoded as a signal, $\mathbf{w}_m$. Second, the signal is modified in preparation for embedding, yielding a modified signal, $\mathbf{w}_a$. Finally, the modified signal is added to the host image, $\mathbf{c}_0$, to obtain the watermarked image, $\mathbf{c}_w$.

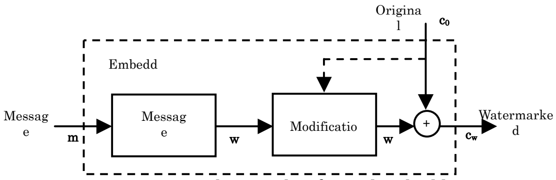

Fig. 1. Watermarking with informed embedding.

It should be noted that the use of cover image in a frequency transform domain (Fourier, wavelet, etc.) prior to embedding may be useful to improve robustness or transparency. In blind embedding, the modification step is performed independently of the cover image; it is usually just a simple, global scaling. In informed embedding, by contrast, the modification is a function of the image and the message signal. Since complete information about the cover image is available, an informed embedder has complete control over the final, watermarked image. That is, it can select any image as $\mathbf{c}_w$ by letting $\mathbf{w}_a = \mathbf{c}_w - \mathbf{c}_0$. The task is to find an image that satisfies two conflicting criteria:

1. $\mathbf{c}_w$ should be similar enough to $\mathbf{c}_0$ to be perceptually indistinguishable, and
2. $\mathbf{c}_w$ should be close enough to $\mathbf{w}_m$ to be detected as containing the watermark, even after distortion by subsequent processing.

We now consider informed coding; in which each message is mapped into a set of alternative codewords and the choice of which codeword to embed is determined by information contained in the cover image.

3. Informed embedding

In the case of informed embedding, the embedding algorithm uses information contained in the host image during the modification stage. However, each message is represented by a unique codeword that is independent of the image. Several researches in communications with side-information at the embedder, suggest that better results can be obtained if the coding process itself is a function of the host image. This is illustrated in Fig. 2.

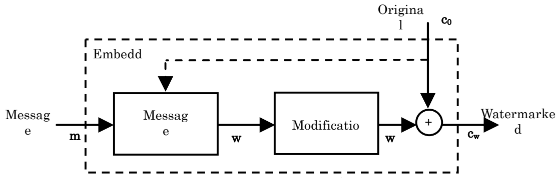

Fig. 2. Watermarking with informed coding.

3.1 Simulation Experiment

In the communication channel paradigm, a message **m** to be transmitted is encoded to $\mathbf{w}_m$. This signal is power constrained since the energy to be send is limited. Similarly, in the case of watermarking, the power constrain is the transparency criterion. Also, the emitted signal is degraded during transmission. This is modelled by the additive Gaussian noise z. Since P (constraint) and N (noise energy) are known, the capacity C of such a channel [9] is computed as follows:

$$C = \frac{1}{2}\log_2\left[1 + \frac{P}{N}\right] \qquad (1)$$

The capacity is the maximal theoretical rate you can reach without any error. Recent error correcting codes such as turbo codes, are quite close to the capacity limit.

3.2 Costa scheme

When restricting our self on the watermarking problem, the watermark $\mathbf{w}_m$ is added to host signal **s**, and then attacked. We model those attacks by the addition of Gaussian noise z. Hence the received signal is $\mathbf{y} = \mathbf{s} + \mathbf{w}_m + \mathbf{z}$. For a Gaussian host signal (with variance Q), the capacity is then,

$$C = \frac{1}{2}\log_2\left[1 + \frac{P}{Q+N}\right] \qquad (2)$$

But a huge difference between this case and the general Gaussian channel is that a part of the interference noise is perfectly known at the embedding phase. Recall that the signal **s** is the side information. In 1983, M. Costa [2] demonstrated that it is possible to design a particular encoding/decoding scheme in order to avoid any influence of side information on capacity.

$$C_{Costa} = \frac{1}{2}\log_2\left[1 + \frac{P}{N}\right] \qquad (3)$$

His proof relied on the use of a codebook in which each message can be represented by a variety of alternative signals. Whereas in classical codes, a message corresponds to a single codeword, Costa codebook associates a set of messages U[**m**] to each possible message **m**. Decoding process consists in looking for the closest codeword to the received signal.

Costa's work was first brought to the attention of the watermarking community by Chen [10], who realized that the cover image can be considered to be a noise source that is perfectly known to the watermark encoder. It is the dirty paper principal, which is described in the following section.

3.3. Dirty-paper code

Using a dirty-paper code, ***U***, to transmit a message, **m**, the transmitter performs the following steps:

1. Identify a closet of the codebook associated with the message, $U_m \subset U$.
2. Search through Um to find the code signal, **u** that is closest to the host signal, s, which will be added by the first noise source (see Fig. 3).
3. Transmit **w** = f(**u**, **s**), where $f(\cdot,\cdot)$ is a function that is analogous to informed embedding. In Costa's construction, f(**u**, **s**)= **u** -a**s**, where a is a constant.

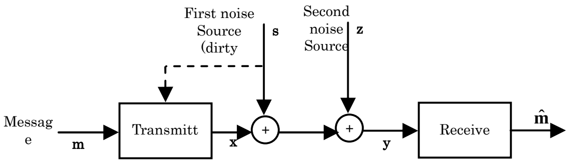

Fig. 3. "Dirty paper" channel studied by Costa.

To decode a received signal, **y**, using a dirty paper code, *U*, the receiver performs the following steps:

1. Search the entire codebook for the closest code signal, $\hat{\mathbf{u}}$.
2. Identify the closet, $U_{\hat{m}} \subset U$, that contains $\hat{\mathbf{u}}$, and report reception of the message, $\hat{\mathbf{m}}$, associated with that subset.

Unfortunately, there is no practical solution to designing a dirty-paper code. Costa's work was based on the use of random codes, and did not address the practical problem of efficient search. With random dirty-paper codes and exhaustive search, it is only possible to implement watermarks with very limited capacity (payloads). Thus, it is necessary to introduce a structured code that allows for more efficient searches.

A number of such codes have been proposed for watermarking. A simple one is to use lattices. The famous scalar Costa scheme [6] is a mono-dimension lattice code (scalar quantization). Whereas they are not as efficient as lattice codes against Gaussian noise, codes based on convolutional trellises [8] [11], provide good performances for watermarking. In their work, Miller et al. [11] proposes a simple modification of a trellis code to produce a dirty-paper code. To create a dirty paper code, the complete trellis is modified so that multiple alternative codewords can be obtained for each message. In the embedding stage, the detection algorithm extracts a vector from the image, and then uses a Viterbi [12] decoder to find the path through the modified trellis that yields the highest correlation with that extracted vector.

A new type of channel coding with side information is based on quantization and turbo principles. Its application to image watermarking shows pretty good performances.

3.4 TTCQ codes for watermarking

In order to perform a source coding technique, Chapellier et al. was extended the TCQ Quantization to turbo principles [13]. This turbo TCQ can be used to design good codes for channels with side information. Based on the results published in [14], turbo TCQ coding, applied to watermarking embedding, carries a gain of about 6 dB compared to QIM/SCS and about 3.8 dB compared to TCQ. The turbo TCQ encoder/decoder is specified as follows.

A first TCQ works on the signal s to be quantized, while a parallel second one works on an interleaved version of s. The obtained sequences are punctured and combined, and then a vector of quantization levels and a path (vector of binary values) are returned. This binary path is then used to embed the binary message components.

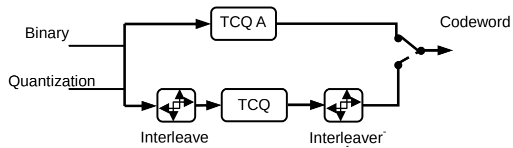

Fig. 4. TTCQ principle: two parallel trellis-coded quantizers.

Turbo TCQ encoding is a variant of dirty-paper coding strategy. Its particularity consists in finding the closest codeword u to the host signal s, while ensuring that returned path corresponds to the message **m** we want to embed. As cited in section 3.3, the added watermark signal is defined as **x** = **u** - α**s**. Similarly to Costa scheme, experiments show that the best value of α is *P* / (*P* + *N*).

4. Proposed watermark embedding

Our global watermark embedding process consists on DWT, watermark embedding based on TTCQ encoding and IDWT. The proposed detection algorithm which is a modified alternative to Miller's iterative solution [11], proceeds as follows:

1. Convert the host image in the wavelet domain
2. Scan the coefficients located at low and high frequency subbands into a single, length $L=M\times N$ vector, in raster order. We refer to this as the *extracted vector* **s**.
3. Use a modified Viterbi decoder to identify through the trellis the path corresponds to the message we want to embed and whose $M\times N$ vector has the highest correlation with the extracted vector.
4. Identify the vector **u** that is closest to the extracted vector.
5. Compute the watermark vector $\mathbf{w} = \alpha(\mathbf{u} - \mathbf{s})$.
6. Add the watermark signal to the extracted vector.

5. Experimental Results

5.1 The watermark robustness and image quality tradeoff

Our analyze criterion is twofold: watermark robustness against the compression attacks, and watermarking impact on the reconstructed image quality. The simulations were conducted for two gray scale images: "Lena" and "X-ray" (extracted from an angiographic sequence), both of size 512x512. As mentioned earlier, two coding schemes, respectively JPEG2000 and SPIHT coders are used in order to evaluate the watermark robustness as a function of the compression rate.

The following set of compression and watermark parameters were fixed: irreversible (9,7) filter-bank; 5 levels of dyadic wavelet decomposition; a watermark message with 1024 bits length. We note that the robustness can be interpreted as the percentage of correct binary symbols extracted for different bitrates. After experimenting with various values of compression bitrates, as showing in Table 1, in the case of X-ray image the watermark message can be entirely extracted for all tested compression bitrates upper than 0.1 bpp. Whereas, for "Lena" image, the entirely message recovery is reached for bitrates upper than 0,2 bpp. Below this bitrate value, the percentage of correct binary symbols is ranging between 82,32% and 73%. Fig. 5, illustrates the Lena image decompressed after a compression with JPEG2000 coder, with and without watermarking embedding. We can notice that the recovered image quality decrease, in term of PSNR is insignificant (of about 0,02 dB).

Fig. 6 shows the X-ray image decompressed after a compression with JPEG2000 coder at 0.2 bpp, with and without watermarking embedding. As cited earlier, the watermark message is entirely extracted. However, the recovered image quality decrease, in term of PSNR, is fairly important (of about 1.62 dB).

It should be noted that for angiographic medical images, the visual quality degradation is highly noticeable for bitrates lower than 0.2 bpp. So, low compression bitrate is not tolerated in a medical practice purpose.

Fig. 5. a) JPEG2000 compressed/decompressed 'Lena' image (PSNR=29.68 dB, 0.1 bpp); b) JPEG2000 compressed/decompressed and watermarked 'Lena' image (PSNR=29.66 dB, 0.1 bpp, *message length*=1024, Recovery rate=73%).

Bitrates			0.1	0.15	0.2	0.4	0.6
Recovery rate	Lena	JPG2000	73%	82,3%	100%	100%	100%
		SPIHT	73%	75%	100%	100%	100%
	X-ray	JPG2000	84,6%	100%	100%	100%	100%
		SPIHT	90,8%	100%	100%	100%	100%

Table 1: Watermark robustness.

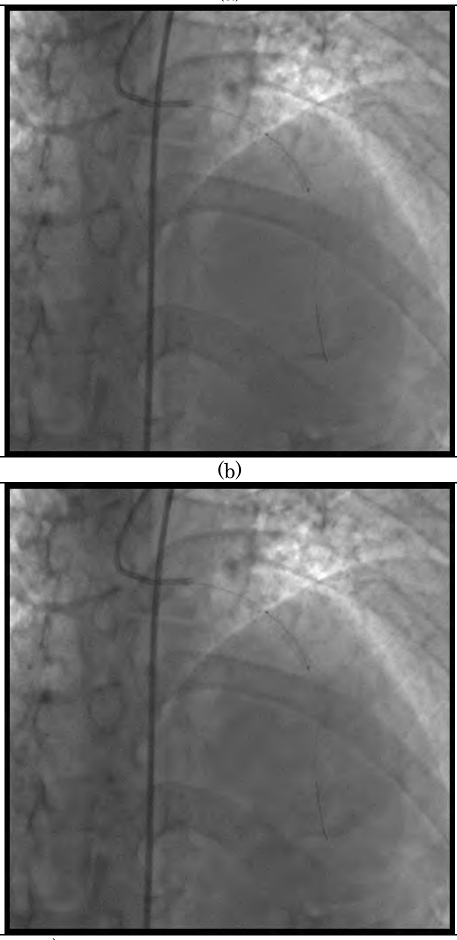

Fig. 6.. a) JPEG2000 compressed/decompressed 'X-ray' image (PSNR=37.8 dB, 0.2 bpp); b) JPEG2000 compressed/decompressed and watermarked 'X-ray" image (PSNR=36.18 dB, 0.2 bpp, *message length*=1024, Recovery rate=100%).

5.2. Embedding capacity comparison with other approaches

The well known watermarking methods based on dirty paper coding, operate in DCT domain. The message is inserted in 8X8 blocs which limits the embedding payloads. Our watermarking scheme allows larger data payloads. As we operate in the wavelet domain, with a variable number of decomposition levels, it is possible to adapt the coefficients (which will be used to encode the watermark message) to the size of message to embed. As shown in Fig 7, for X-ray image, we can embed 32 768 bits message length with respect to the subjective/objective recovered image quality. However, with the DCT methods, the tolerated message length is 4096 bits (due to the 8x8 blocs decomposition) with a PSNR = 41,87dB. This result was obtained using TTCQ quantization approach in the DCT domain. Moreover, for the same embedding payload size (4096 bits), our algorithm provides higher PSNR value of about 54,79dB. Meerwald's watermarking algorithm [15] integrated to JPEG2000 coding engine, exhibits a high performance in term of reconstruction quality. However, the watermark correlation starts to decrease for bitrates less than 0.15 bpp. Also, the watermark message length is relatively short, of about 85 bits for Lena image, which still negligible compared to our watermarking scheme's capacity.Recently, a JPEG2000 based image authentication scheme was developed [16] by using an extended scalar quantization and hashing scheme in JPEG2000 coding chain. This hybrid system yields impressive robustness of the embedded watermark but it induces a high quality degradation, in term of PSNR, that can reach 10 dB.

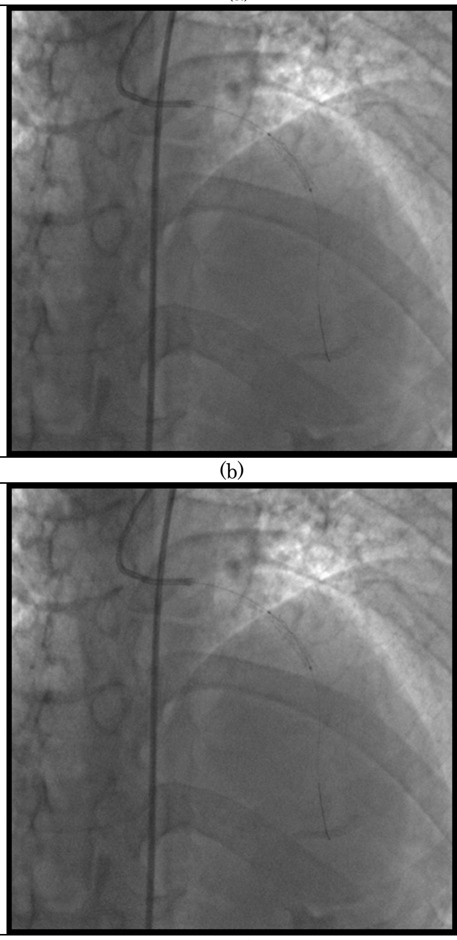

Fig. 7. a) Original "X-ray" image of size 512×512; b) Watermarked 'X-ray" image (PSNR= 47,13 dB, message length = 32768 bits)

4. Conclusion

We have presented here a new approach for image watermarking scheme which has been validated by successfully resisting to wavelet based compression attacks. The watermarking method itself relies on discrete wavelet transform of the cover image. The message is encoded in the spread spectrum signal. The Costa's scheme and TTCQ codes were studied and exploited in order to generate this spread spectrum sequence. Experimental results show on one hand the robustness of our watermark detection algorithm against wavelet-based compression attacks and, on the other hand, the important embedding payloads with the respect to the subjective/objective watermarked image quality. It should be noted that this work is quite preliminary and some investigations can be carried out to optimize the trade-off between watermark robustness and minimum quality degradation. As an example, it is important to incorporate perceptual shaping, based on Watson's perceptual distance measure to reduce the perceptual distance between watermarked and unmarked images.

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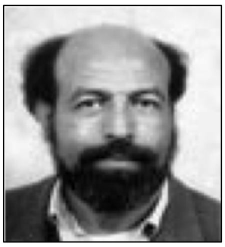
Azza Ouled Zaid was born in Tunis, Tunisia, in 1974. She received the electric engineering degree from the engineering school of Sfax in Tunisia in 1997. She received Master. degree of Captors and instrumentation for vision systems in 1999, from L3I Laboratory, the Rouen University in France She received Ph.D. degree in 2002, from SIC Laboratory, the Poitiers University in France with a thesis on the optimization of image coding. In 2003-2004 she was working as a research assistant in LSS Laboratory from Supelec Engineering school in Paris France. From 2004, she is an associate professor in computer science institute, Department of network system administration, in Tunis Tunisia. Her research interest includes Image compression, source canal coding, watermarking, ans medical image processing.

Achraf Makhloufi was born in Sfax, Tunisia, in 1976. he received the electric engineering degree from the engineering school of Gabes in Tunisia in 2001. He received Master. degree in 2003, from the engineering school of Sfax in Tunisa. From 2004 he is a Ph.D. student in SYSCOM Laboratory in Tunis engineering school (Tunisia). His research interest includes watermarking and image coding.



Ammar Bouallegue was born in Tunis, Tunisia, in 1962. He received the electrical engineering, and engineer doctor degrees from ENSERG of Grenoble, France, in 1971 and 1975, respectively, and the Ph.D. degree from ENSEEIHT, INP of Toulouse, France, in 1984. In 1976, he joined the Engineering school of Tunis (ENIT), Tunisia. From 1986 to 1994, he was Manager of the Electrical Department, ENIT, and from 1994 to 1996, he was Director at Telecommunication high school of Tunis, Tunisia. He is currently Manager of SYSCOM Laboratory at the Engineering school of Tunis. His research interests include passive and active microwave structures and signal coding theory and image processing, watermarking.