

# Capacity improvement in digital watermarking using QCM scheme

*Santi P. Maity*<sup>1</sup>, *Malay K. Kundu*<sup>2</sup>, *Seba Maity*<sup>3</sup>

Bengal Engg. and Sc. University, Shibpur, P.O.-Botanic Garden, Howrah, India, 711 103<sup>1</sup>

Machine Intelligence Unit, 203 B. T. Road, Kolkata, India, 700 108<sup>2</sup>

Narula Inst. of Technology, 81, Nilgunj Road, Agarpara, Kolkata 700109

*spmaity@telecom.becs.ac.in*<sup>1</sup>, *malay@isical.ac.in*<sup>2</sup>, *sebamait@yahoo.co.in*<sup>3</sup>

*Abstract:*

Quadrature Carrier Multiplexing (QCM) allows simultaneous transmission of two message signals over the same bandwidth using quadrature carriers of the same frequency. This principle is used in this work to improve embedding capacity in digital image watermarking using wavelet transforms. Biorthogonal wavelet filters are used to design Hilbert transform (HT) pair and symmetric filter coefficients reduce computation cost significantly in watermarking. Hilbert transform (HT) pair decompose the cover image in two quadrature directions so that the effect of inter symbol interference (ISI) is reduced to the minimum level and embedding capacity is increased two times although there occurs almost no degradation in robustness performance. Spread spectrum (SS) modulation technique further improves robustness performance and spreading codes are designed based on the selection of wavelet sub bands so that host signal interference is reduced significantly. Experiment results show that watermark decoding from both the decompositions are affected in the similar fashion over a wide range of signal degradation.

**Keywords:** Spread Spectrum watermarking, wavelet transformation,  $M$ -ary modulation, lossy compression.

## 1 Introduction

Many researchers view digital watermarking algorithms as an imperceptible, robust, and secure communication of watermark information by embedding in and retrieving it from other digital data [1]. In the literatures of digital watermarking, it is an established fact that imperceptibility i.e. embedding distortion, robustness and hiding capacity are related with each other in a contradictory fashion in three dimensional problem space. Digital communication model of watermarking, under certain circumstances, increases data hiding capacity with greater robustness while embedding distortion

is held to an almost constant value. Among the most commonly used watermark insertion approaches, spread spectrum (SS) modulation based algorithms are found to be efficient, robust and cryptographically secured. Although various SS watermarking methodologies [2]-[4] are found in the literatures, the scheme that uses distinct bi-valued spreading codes (signature) is the most popular one.

An important challenge in digital watermarking is to develop algorithm that allows multiple message embedding or improvement in embedding rate with marginal degradation in robustness performance and data imperceptibility. Quadrature carrier multiplexing principle can be used to meet the goal by embedding two different watermarks after projecting the cover signal into two quadrature directions. Hilbert transform pairs provide two quadrature decompositions of the carrier signal, although, efficient realization of Hilbert transform pair is an open design problem.

The present work proposes QCM-SS modulation based digital watermarking algorithm where quality of the marked image is degraded marginally even after two times increase in embedding capacity. Biorthogonal wavelet bases form approximate Hilbert transform pair while shorten the length of the filter coefficients efficiently. Simulation results also show that both the watermarks are affected equally for a particular degradation simulated over the watermarked images.

## 2 QCM for SS watermarking

Maity et al [4] developed the properties of the code patterns for improved SS detection. Robust and high capacity SS watermarking can be designed if image signal is decomposed in proper direction as well as in different directions so that low correlation value with the code patterns can be achieved in each decomposition. Fig. 1 shows the correlation between code pattern and image decomposition corresponding to three selected wavelets. Three wavelets

are Daubechies 2 tap, biorthogonal (6,8) and (4,4). It is observed that biorthogonal wavelet decomposition, possibly due to the complementary information of the two wavelet systems, offers better directional selectivity compared to classical wavelet transform [5] and yields lower correlation with the code patterns.

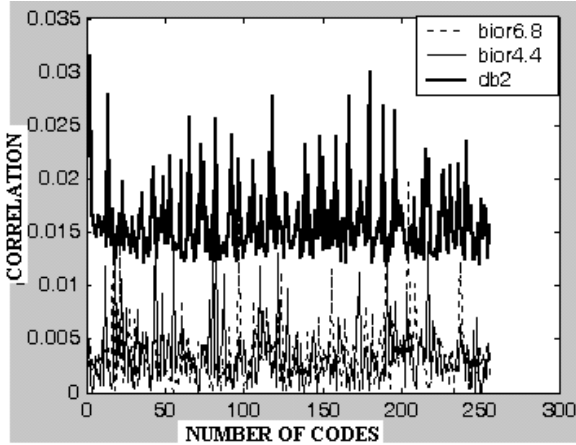


Figure 1: Correlation between code pattern and image decomposition using a few selected wavelets

Design of digital watermarking algorithm using QCM principle demands efficient realization of Hilbert transformation using wavelet transform as the transformation becomes appealing due to its space-frequency localization, multi-resolution representation, superior HVS (human visual modeling) and adaptivity. Two watermark signals can be embedded by decomposing the cover image using Hilbert transform pair and two wavelet bases can be used for the purpose where one wavelet is (approximately) the Hilbert transform of the other. Computation cost associated with the design of Hilbert transform pair is an important issue as low computation cost is an essential requirement of digital watermarking. The novelty of the paper lies in the efficient realization of Hilbert transform pair using biorthogonal wavelet for the design of robust SS watermarking with greater embedding capacity.

### 3 Design of Hilbert transform from wavelet bases

Implementation of QCM based watermarking scheme in wavelet domain requires two wavelet bases where one wavelet is (approximately) the Hilbert transform of the other. The use of two wavelet bases are found in the literatures for transient detection, turbulence analysis, and waveform encoding [6] etc. The important question is how one can choose low-pass filters  $h_o$  and  $g_o$  so that the two wavelets will

form a Hilbert transform pair.

Let us recall the definition of Hilbert transform.  $\psi_g(t)$  is the Hilbert transform of  $\psi_h(t)$  if

$$\psi_g(\omega) = \begin{cases} -j\psi_h(\omega) & \text{if } \omega > 0 \\ j\psi_h(\omega) & \text{if } \omega < 0 \end{cases}$$

In [6] I. W. Selesnik established the relations between  $\phi_g(t)$  and  $\phi_h(t)$ ,  $G_1(\omega)$  and  $H_1(\omega)$ ,  $\psi_g(t)$  and  $\psi_h(t)$  assuming that the two lowpass filters are related as follows:

$$G_0(\omega) = H_0(\omega)e^{-j\theta(\omega)} \quad (1)$$

where  $\theta(\omega)$  is  $2\pi$  periodic. The relations among the above mentioned pairs are established in the paper as follows:

$$\phi_g(\omega) = \frac{\phi_g(0)}{\phi_h(0)}\phi_h(\omega)e^{-j\sum_{k=1}^{\infty}\theta(\frac{\omega}{2^k})} \quad (2)$$

$$G_1 = H_1e^{j\theta(\omega-\pi)} \quad (3)$$

and

$$\psi_g(\omega) = \phi_h(\omega)e^{j[\theta(\omega/2-\pi)-\sum_{k=2}^{\infty}\theta(\frac{\omega}{2^k})]} \quad (4)$$

If  $H_0(\omega)$  and  $G_0(\omega)$  are lowpass CQF (conjugate quadrature filter) with

$$G_0(\omega) = H_0(\omega)e^{-j(\omega/2)}, \text{ for } |\omega| < \pi \quad (5)$$

then the corresponding wavelets are a Hilbert transform pair i.e.  $\psi_g(t) = \mathcal{H}[\psi_h(t)]$

Equivalently, the digital filter  $g_0(n)$  is a half-sampled delayed version of  $h_0(n)$

$$g_0 = h_0(n - 1/2) \quad (6)$$

As a half-sample delay can not be implemented with FIR (finite impulse response) filter, it is necessary to make an approximation. Now, based on the number of zero wavelet moments and the parameter for controlling the half-sample delay approximation, a set of design equations need to be solved for the design of the filters  $h_0$  and  $g_0$  of minimal length. The filter coefficients, for an example, can be found as in Table 1 where  $N$ ,  $L$  and  $K$  denote the length of the wavelet filter, parameter for controlling the half-sample delay approximation and the number of zero wavelet moments respectively.

The shortcomings of the method is that the designed wavelet filters are always of the same length (even for different values of  $K$  and  $L$ ) and non linear phase for the restriction of approximation degree at zero. Better approximation to Hilbert transform pairs requires longer length of wavelet filter band and a much higher order equations to solve in design and more computation cost in applications.

Table 1: Filter coefficients of Hilbert transform approximately for  $N = 10$ ,  $K = 4$ ,  $L = 5$

$h_0(n)$	$g_0(n)$
0.03221257407420	0.01123179664593
0.00820937853576	0.0293846247110
-0.06023981115681	-0.02941520794631
0.2973132183851	0.05228807988494
0.79149943086392	0.56614863255854
0.51279103306800	0.77383926442488
-0.05414137333876	0.21123282805692
-0.11999180398584	-0.16831623167690
-0.00222403925601	-0.05209126812854
-0.00872685173012	0.01991104128252

In the paper the above mentioned design problems of Hilbert transform are taken care using biorthogonal wavelet bases. It is also mentioned in section 2 that biorthogonal wavelet bases decompose the cover image to the directions that yield low correlation with the spreading code.

If  $[H_0(z), H_1(z); \tilde{H}_0(z), \tilde{H}_1(z)]$  and  $[G_0(z), G_1(z); \tilde{G}_0(z), \tilde{G}_1(z)]$  are the two biorthogonal wavelet filter banks, then the following two relations are equivalent.

- (i)  $\psi_g(t) = \mathcal{H}[\psi_h(t)]$  and  $\tilde{\psi}_g(t) = -\mathcal{H}[\tilde{\psi}_h(t)]$
- (ii)  $\hat{G}_0(\omega) = e^{-j\omega/2}\tilde{H}_0(\omega)$  and,  $|\omega| < \pi$ .

If biorthogonal wavelets  $\psi_h(t), \tilde{\psi}_h(t)$  and  $\psi_g(t), \tilde{\psi}_g(t)$  form a Hilbert transform pair, then the corresponding scaling filter pairs have the following relationship:

$$G_0(z) = z^{-1/2}H_0(z), \tilde{G}_0(z) = z^{1/2}\tilde{H}_0(z)$$

or

$g_0 = h_0(n - 1/2)$ ,  $\tilde{g}_0 = \tilde{h}_0(n + 1/2)$  where  $h_0$  are the coefficients or responses of  $H_0(z)$ .

If we assume  $[H_0(z), \tilde{H}_0(z)]$  and  $[G_0(z), \tilde{G}_0(z)]$  are FIR filters, and both satisfy the corresponding PR (perfect reconstruction) condition  $P(z) + P(-z) = 2$ , where  $P(z) = H_0(z)\tilde{H}_0$ , filter coefficients can be found by minimizing the following relation:

$$\int_0^\pi (|\hat{E}(w)|^2 + |\hat{\tilde{E}}(w)|^2)dw \quad (7)$$

where  $\hat{E}(w) = \hat{G}_0(2w) - e^{-jw}\hat{H}_0(2w)$  and  $\hat{\tilde{E}}(w) = \hat{\tilde{G}}_0(2w) - e^{jw}\hat{\tilde{H}}_0(2w)$ . The better approximate to Hilbert transform pair is achieved when  $E(z)$  is closer to zero. If the analysis and the synthesis part is considered separately, the objective function (10) can be replaced by

$$\min_\alpha \int_0^\pi (|\hat{E}(w)|^2)dw \quad (8)$$

where  $\alpha$  denotes the parameter set of biorthogonal wavelet filters to be designed. The optimal param-

eter  $\alpha^*$  determines  $H_0(z), \tilde{H}_0(z), G_0(z), \tilde{G}_0(z)$  and wavelet functions can be obtained from scaling and wavelet equations. If we assume  $(L_h, \tilde{L}_h) = (7, 9)$ ,  $(L_g, \tilde{L}_g) = (8, 9)$ ;  $(K_h, \tilde{K}_h) = (5, 1)$  and  $(K_g, \tilde{K}_g) = (5, 1)$ , the following coefficients values are found.

Table 2: The scaling filter coefficients of biorthogonal wavelet bases forming a Hilbert transform approximately

$h_0(n)$	$h_0(n)$	$g_0(n)$	$\tilde{g}_0(n)$
0	0.0095	0	0.0428
-0.0125	0.0264	-0.0200	-0.0615
0.0375	-0.2321	-0.0287	-0.1272
0.2625	0.2216	0.1363	0.6458
0.4250	0.9454	0.4125	0.6458
0.2625	0.2216	0.4125	-0.1271
0.0375	-0.2321	0.1363	-0.0615
-0.0125	0.0284	-0.0287	0.0428
0	0.0095	-0.0200	0

The filter coefficients of Table 1 and Table 2 show that the wavelet functions are smoother in case of biorthogonal wavelet bases. Furthermore, the coefficients of filters in Table 2 are symmetric, while in Table 1 are asymmetric. These properties are quite advantageous to the digital watermarking as well as other image processing applications where shorter length and symmetric coefficients of filters can reduce the computation efficiently to about one third of the original.

## 4 Proposed watermarking technique

In this section, we present the proposed QCM based spread spectrum watermarking technique. The watermarked image  $I_W$  can be obtained by embedding watermark information  $W$  into the image block  $I$ . The data embedding can be expressed mathematically as follows:

$$[(I_w)_M] = [I_M] + k \cdot [W_M] \quad (9)$$

where a set  $P$  of  $N$  code patterns, each of length  $M$ , are generated to form watermark sequence  $W_M$  by performing the following operation.

$$[W_M] = \sum_{j=1}^N b_j \cdot [P_M]_j \quad (10)$$

In the above equations,  $b_j$ s represent message bits and  $k$  is the gain factor or modulation index.

The cover image is decomposed in two different directions using the filter coefficients given in

Table 2. Biorthogonal wavelet bases form a Hilbert transform pair approximately. For each binary valued message bit, pseudo noise (PN) matrix of size identical to the size of the wavelet coefficient matrix is then generated and is modulated by W-H matrix. The modulation is done by performing exclusive-OR operation of code pattern with W-H matrix. This modulated code pattern  $pn_a$  is used to embed data in the LL sub band. An orthogonal code pattern  $pn_d$  is obtained by complementing the bits of  $pn_a$ , and is used for data embedding in the HH sub-band. If the size of a watermark image is  $(M_w \times M_w)$ , the total number of required code patterns would be  $M_w^2$ . To improve robustness in binary modulation, antipodal embedding scheme is used as follows:

$$X^e = \begin{cases} X + \alpha.P & \text{if } b = 0 \\ X - \alpha.P & \text{if } b = 1 \end{cases}$$

where  $X$  represents the wavelet coefficients of the cover image,  $X^e$  the wavelet coefficients after watermark embedding,  $\alpha$  is the modulation index,  $P$  is the PN matrix. Two different binary watermarks are embedded in two different decomposition of the cover obtained by using two different Hilbert transforms. Quadrature decomposition, due to orthogonality, allows the use of single set of spreading codes for embedding two watermarks in the same cover.

To decode message bit, two correlation values (one from LL and other from HH sub band) are calculated and total  $M_w^2$  (total number of watermark bits) number mean correlation values ( $\mu_i$ ) are obtained where  $i = 1, 2, ..M_w^2$ . From these mean correlation values, we calculate an overall mean correlation value ( $T$ ) that is used as the threshold for watermark decoding. The decision rule for the decoded watermark bit is as follows:

- if (i)  $\mu_i \geq T$ , the extracted bit is '0' and
- if (ii)  $\mu_i < T$ , the extracted bit is '1'.

## 5 Performance evaluation

The watermarks are binary images of size  $(16 \times 16)$  and the cover image is a gray-scale image of size  $(256 \times 256)$ , 8 bits/pixel. The proposed algorithm requires approximately 5 seconds for watermark embedding and approximately 3 second for extraction using the filter coefficients of Table 2 in Visual C/C++ platform running on a Pentium III 400 MHz PC system. The watermark embedding and decoding process requires 11 seconds for embedding and 7 seconds for decoding in the same computation platform using the filter coefficients of Table 1. In this paper, we use both Peak Signal to Noise Ratio (PSNR) and mean Structural Similarity index (MSSIM)[7] to quantify invisibility of

the hidden data. MSSIM is the mean of the SSIM values and represents image quality by a single numerical value with its highest value 1 corresponds to no distortion. Fig. 2(a) shows the test image Fishing Boat of size  $(256 \times 256)$  and binary watermark images are shown in Figs. 2(b)-2(c). Although the experiment has been performed over large number of cover images, however, Table 3 shows the effect of two message embedding on data imperceptibility for the few cover images. Results in Table 4

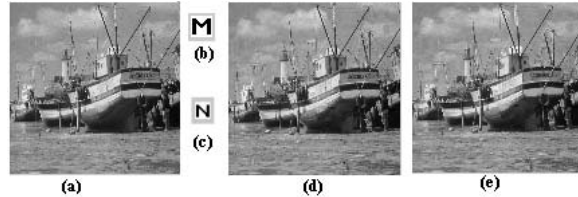


Figure 2: (a) Test image, (b)-(c) watermark images, (d) watermarked images after embedding two watermarks using coefficients of table 2, (e) watermarked images after embedding two watermarks using coefficients of table 1

Table 3: Data imperceptibility after embedding two different watermarks

Test images	PSNR(dB) after single message	PSNR(dB) after two messages	MSSIM after single message	MSSIM after two messages
Lena	35.47	35.45	0.9536	0.9514
Boat	35.47	35.36	0.9623	0.9612
Pills	34.23	34.09	0.9454	0.9387
Opera	36.78	36.56	0.9645	0.9634

show that embedding distortion in the present case is much lower than [4] as it is found that PSNR values after embedding two messages are 35.45 dB for the present algorithm and 31.05 dB for the latter algorithm.

Table 4: Comparison of data imperceptibility; first row for the proposed algorithm and last row for algorithm in [4]

Test image	PSNR(dB) after single message	PSNR(dB) after two messages	MSSIM after single message	MSSIM after two messages
Boat	35.47	35.45	0.9536	0.9514
Boat	36.27	31.05	0.9623	0.9132

We have evaluated the performance of the proposed technique in several compression frameworks. However, we present here only the results corresponding to JPEG and JPEG 2000 compression framework. Fig. 3 shows the robustness performance of two message embedding against JPEG and JPEG 2000 compression operations. At a particular quality factor probability of decoding error

for both the watermark images are almost same for a given compression framework. This indicates that QCM watermarking scheme offers the same robustness performance for the watermarks embedded in two decompositions. As expected, due to wavelet domain embedding, robustness performance of the proposed algorithm against JPEG 2000 compression is better compared to JPEG compression. This is indicated in Fig. 3 by low probability of error values for the decoded watermarks in case of JPEG 2000.

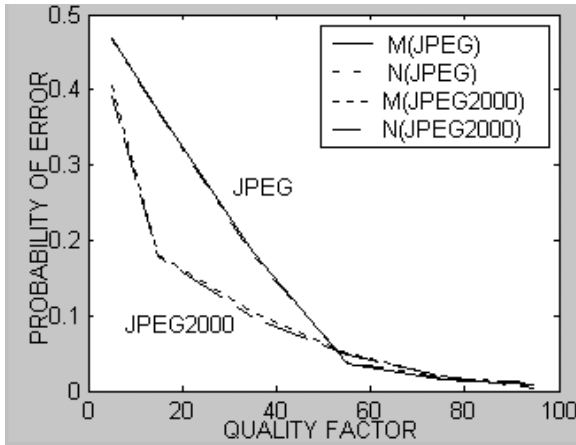


Figure 3: Robustness performance against JPEG and JPEG 2000 compression operations for the two watermarks embedded in two quadrature decompositions

Fig. 4 shows the robustness performance of the proposed algorithm against additive gaussian noise. Robustness performance is decreased with the increase of the variance value of the noise. As expected, QCM watermarking scheme, offers the similar performance variation for both the decoded watermarks when watermarked images are corrupted by additive noise.

## 6 conclusion

The paper proposes digital image watermarking scheme based on QCM principle where data embedding rate is increased twice with negligible loss in image quality and almost no performance degradation. Approximate Hilbert transform pairs generated from biorthogonal bases can reduce the computation efficiently for image processing application due to the shorter length and symmetric coefficients of the filters. Moreover, biorhogonal wavelet filters of linear phase can also be designed. It is also found that watermarks embedded in two quadrature decompositions are affected in the similar fashion when various signal processing operations are simulated over the watermarked images.

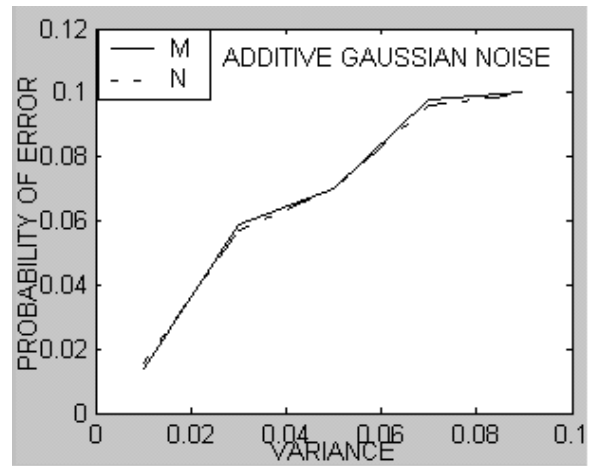


Figure 4: Robustness performance against additive gaussian noise operations for the two watermarks embedded in two quadrature decompositions

## References

- [1] J. Eggers, and B. Girod, *Informed watermarking*, Kluwer academic publishers, Boston, 2002.
- [2] I. J. Cox, J. Kilian, T. Leighton, and T. Shanon, "Secure spread spectrum watermarking for multimedia," *IEEE Trans. on Image Proc.*, 6:1673-1687, 1997.
- [3] J. O. Ruanaidh and T. Pun, "Rotation, scale and translation invariant spread spectrum digital image watermarking," *Signal Proc.*, 66:303-317,1998.
- [4] S. P. Maity, M. K. Kundu and T. S. Das, "Design of a robust spread spectrum image watermarking," *4th ICVGIP*, PP. 145-150, Kolkata, December 2004.
- [5] C. S. Burrus, R. A. Gopinath and H. Guo, *Introduction to wavelets and wavelet transforms, A Primer*, Prentice Hall, Upper Saddle River, NJ, 1997.
- [6] I. W. Selesnick, "Hilbert transform pairs of wavelet bases," *IEEE Signal Processing Letters*, 8:170-173, 2001.
- [7] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image quality assessment: From error measurement to structural similarity," *IEEE Trans. on Image Proc.*, 13:1-14, 2004.