Robustness improvement in spread spectrum watermarking using M-ary modulation

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Abstract

Spread spectrum (SS) modulation principle is widely used in digital watermarking to satisfy the robustness criterion against various common signal processing operations as well as deliberate external attacks. Several SS image watermarking schemes have been developed in various transform domains such as DCT (discrete cosine transform), DHT (discrete Hadamard transform), Fourier-Mellin, and Wavelet etc using binary signaling. The use of wide spectrum of the cover data in message hiding process puts a limit on data rate subject to a given embedding distortion. The paper investigates the scope of using M-ary modulation principle for performance improvement over binary signaling scheme. The current work also suggests data embedding in selected sub bands using DWT (discrete wavelet transform) and MbDWT (M-band wavelet transform) decomposition. Performance improvement of M-ary signaling principle in SS scheme and superiority of wavelet domain embedding over spatial domain approach are also supported by numerical results against JPEG and JPEG 2000 compression operations.
Index Terms: Channel coding, M-ary modulation, Spread Spectrum watermarking, wavelet transformation

1 Introduction

Digital watermarking algorithms can be thought as digital communication scheme where an auxiliary message is embedded in digital multi media signals and are available where ever the latter signals move. The decoded message later on serves the purpose of copyright protection, data authentication, security in communication, broadcast monitoring etc [1]. Robustness is an essential criterion in digital multimedia watermarking schemes along with visual transparency, high embedding rate, low computation cost and complexity of the algorithms needed for data embedding and recovery purposes. All these requirements are related in conflicting manner and the particular algorithmic development emphasizes to a greater extent on one or more such requirements depending on the type of applications [2].

In digital communication spread spectrum modulation technique offers anti jamming and interference rejection property [3]. Motivated by this attribute several researchers developed SS watermarking algorithms for multimedia signals either in original domain [4] or in transform domain by using DCT [5], Fourier-Mellin [6], DHT [7], and wavelet decomposition [8]. SS watermarking schemes, although can be implemented in various different ways, the method that uses distinct pseudo noise (PN) spreading codes for embedding each binary digit is popular and is proven to be efficient, robust and cryptographically secure. At this point the use of various channel coding schemes and M-ary modulation technique can be found efficient for robustness improvement as they are widely used in digital communication for increasing data transmission reliability. While channel coding scheme reduces data transmission rate for improving reliability, M-ary principle of certain modulation schemes improve detection performance by increasing the number of transmitted symbols.

In the applications of digital image watermarking the concept of channel coding scheme becomes inefficient due to the problem of finding out the appropriate code lengths. The problem arises because of the variable nature of channel distortion that depends on the cover data size, content and the nature of deliberate attacks applied to the stego data [9]. For a given length of binary message and fixed embedding distortion, M-ary signaling schemes offer higher resiliency over binary modulation scheme since less number of modulation functions will be required in the latter case that gives rise the scope of choosing higher modulation index values. Robustness performance for different M-values are reported through graphical representations and the results also highlight higher resiliency of wavelet domain embedding over spatial domain approach.

The paper is organized as follows: Section 2 discusses SS watermarking principle while section 3 presents M-ary modulation and demodulation in SS watermarking. Section 4 describes the conditions and consideration under which the experiment is carried out. Sections 5 and 6 present some experiment results and conclusions respectively.

2 SS watermarking principle

Let B denotes the binary valued watermark bit string as a sequence of N bits.

$$B = \{b_1, b_2, b_3, ..., b_N\}, b_i \epsilon \{1, 0\} \quad (1)$$

If image block I contains M number signal points , a binary valued code pattern of length M is used to spread each watermark bit. Thus a set P of N code patterns, each of length M, are generated to form watermark sequence W by performing the following operation [10].

$$[W_M] = \sum_{j=1}^{N} b_j.[P_M]_j \quad (2)$$

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:

$$[(I_w)_M] = [I_M] + \alpha.[W_M] \quad (3)$$

where α is the gain factor or modulation index and its proper choice will optimize the maximum amount of allowed distortion and minimum watermark energy needed for a reliable detection. α may or may not be a function of image coefficients. Accordingly SS watermarking schemes can be called as signal adaptive or non adaptive SS watermarking.

In SS watermarking the detection reliability for the binary valued watermark data depends on the decision variable t_i obtained by evaluating the zero-lag spatial cross-covariance function between the image I_w and each code pattern P_i [11]. The decision variable t_i can be mathematically represented as follows:

$$t_i =< P_i - m_1(p_i), I_w - m_1(I_w) > (0) \quad (4)$$

where $m_1(S)$ represents the average of the sequence S. If s_k represents the elements of S with k=1,2,..M, $m_1(S)$ can then mathematically be expressed as follows:

$$m_1(S) = 1/M \sum_{k=1}^{M} s_k \quad (5)$$

The symbol (0) in equation (4) indicates the zero-lag cross-correlation and for two sequences S and R, the zero-lag cross-correlation is given by

$$< S, R > (0) = 1/M \sum_{k=1}^{M} s_k r_k \quad (6)$$

where s_k and r_k are the elements of sequences S and R respectively with k=1,2,3......M. The bit b_i is detected as zero if $t_i > 0$ and as '1' otherwise. If the code patterns P_i are chosen so that $m_1(P_i)$=0 for all i, the computation of t_i becomes;

$$t_i = < P_i, [I + \alpha. \sum_{j=1}^{N} b_j.P_j - m_1(I)] > \quad (7)$$

$$= < P_i, I > + \alpha. \sum_{j=1}^{N} b_j. < P_i.P_j > - < P_i, m_1(I) > \quad (8)$$

$$= < P_i, I_w > \quad (9)$$

The above analysis indicates that code patterns used for spread spectrum watermarking should possess some specific properties [12]. Watermark detection is improved if the following conditions are satisfied:

(1) P_i, i=1,2, ... M, should be distinct sequences with zero average.

(2) The spatial correlations $< P_i, P_j >$,j$\neq i$ should be minimized. Ideally, sequences P_i and P_j should be orthogonal whenever $j \neq i$.

(3) Each P_i for i=1,2,....M should be uncorrelated with the image block I when image prediction (for estimating the image distortion) is not used before evaluating the cross-correlation.

3 M-ary modulation and demodulation in SS watermarking

In digital communication the smallest information entity is called as symbol where in binary signaling there are two different symbols and in M-ary ($M > 2$) signaling there are more than two number of different symbols. The M in M-ary refers to the number of symbols used in communication scheme. From communication theory we know that for certain modulation scheme an increase in the number of the symbols decreases the symbol error probability. Now the use of M-ary modulation in digital watermarking is discussed in the following paragraph.

In M-ary signaling if more number of bits are used to represent a symbol of a fixed length binary message, the fewer number of symbols need to be hidden in the cover image. In the spatial SS watermarking scheme fewer symbols decrease the error probability by providing the more locations of embedding for each symbol. In transform domain SS watermarking scheme the improvement in performance due to the usage of M-ary modulation can be explained as follows. When more number of bits are used to form a symbol i.e. the larger the value of M, less be the numbers of symbols need to be hidden for a given length of binary message and there is the scope of choosing higher modulation index value. In other words for a given embedding distortion, higher modulation index value can be chosen in M-ary signaling compared to binary signaling. The higher modulation index values improve robustness performance i.e. reliability of transmission through noisy channel.

Fig. 1 shows the block diagram of M-ary modulation based SS watermark embedding scheme. M-ary modulation scheme first maps a L bit long message (say) of two symbols signal to M different symbols message by grouping $\log_2(M)$ bits of the original message to one symbol. Each symbol is represented by a bi-level spread spectrum modulation function (PN matrix) and the total number of functions in the basis set S_i (where i= N) should be equal to the total number of symbols N in the symbol messages. So if M ($= 2^m$, where each symbol is represented by m bits) and N represent the number of different distinct symbols and total number of symbols in the symbol message respectively, we need M different sets of code patterns each having N number of bi-level modulation functions.

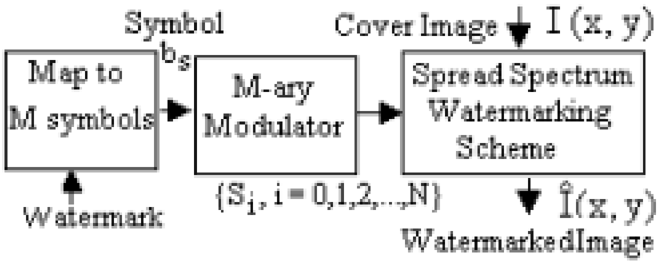

Figure 1: Block diagram of M-ary modulation based SS watermarking scheme

Fig. 2 shows the block diagram of watermark decoding in M-ary system. To decode a symbol at one particular position, correlation between the embedded image block and the modulation functions of that particular position for all the sets of keys are calculated. The index of the largest correlation coefficient i.e. the particular set of key whose modulation function of respective position yields the maximum correlation value determines the decoded symbol.

4 Design of experiment

We employ M-ary modulation in SS data embedding for digital images although the experiment can

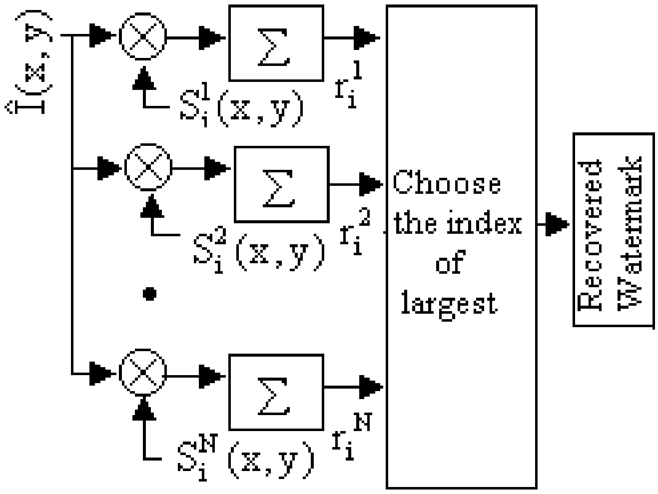

Figure 2: Block diagram of watermark decoding in M-ary system

also be done for other kind of data like audio, music, video etc. The cover image I is a gray-level image of size $(N \times N)$ where $N = 2^p$ and the reference watermark W is a binary image of size $(M \times M)$ where $M = 2^n$. The values of p and n, indicate the size of the cover and the watermark image where $p > n$, typically $(p/n) \geq 4$. The proposed work considers a binary image of size (16×16) as watermark and (256×256), 8 bits/pixel gray image as cover image. In order to show the better comparison of M-ary modulation scheme, data is embedded separately in spatial (directly in pixel values) domain as well as in transform domain. Although there are many transformation such as DCT, DFT, Fourier-Mellin, DHT etc. but we use here discrete wavelet transform (DWT) as it attracts attention in various image processing applications including digital image watermarking, detection, de noising and the upcoming image compression standard JPEG-2000 due to its co-joint representation of the image signal [13]. The normal DWT (2 band system) decomposes an image signal into LL (low-low), LH (low-high), HL (high-low) and HH (high-high) sub bands while the M-band discrete wavelet transformation (MbDWT) system decomposes the same into $(M \times M)$ channels, corresponding to different direction and resolutions [14]. In case of DWT decomposition these sub bands correspond to the coarse approximation, horizontal, vertical and diagonal detail of the image signal respectively. In order to accomplish better spectrum spreading we embedded data in LL and HH sub bands (2 band system) and few selected channels (M-band system) with low and high variance values. In the case of M-band wavelet decomposition (where M=4) results obtained from the large number of images show that

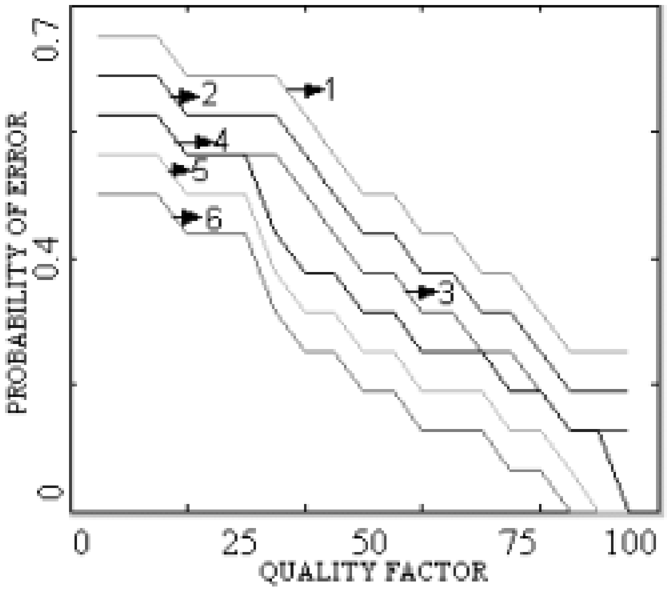

Figure 3: Robustness performance: curves 1, 2, 3 for spatial, DWT and M-band decomposition for M=2-ary modulation respectively; curves 4, 5, 6 for spatial, DWT and M-band decomposition for M=4-ary modulation respectively

the variance values for the coefficients of subbands H_{12}, H_{13}, H_{14} H_{24} are always in the lower range and for the sub bands H_{41}, H_{42}, H_{43}, H_{31}, are in the upper range. A set of binary valued pseudo Number (PN) equal to the size of image block are generated and for each (PN) matrix the orthogonal code ($\overline{PN}$) is obtained by complementing the bits of (PN) code. Each (PN) matrix and ($\overline{PN}$ matrix are modulated by one row of Hadamard matrix with proper dimension. Hadamard basis is used to decrease cross-correlation among PN codes. This is possible since rows and columns are orthogonal to each other. If the code PN is used for data embedding in LL sub band (H_{12}, H_{13}, H_{14} H_{24}), the orthogonal code ($\overline{PN}$) obtained by complementing the bits of PN code are used for data embedding in HH sub band (H_{41}, H_{42}, H_{43}, H_{31}). The use of PN and ($\overline{PN}$) indicates low correlation of code patterns with the corresponding image blocks i.e. sub bands or channels and property (3) of the code pattern is thus fulfilled.

5 Results and discussion

SS watermarking scheme is applied over large number of bench marked images [15]. Data is embedded separately in spatial domain, LL and HH sub bands obtained after DWT decomposition and few selective sub channels of low and high variance blocks after M-band decomposition. The performance of M-ary modulation are shown in Figs. 3, 4 and 5 where it is quite clear that with the increase of M-value robustness efficiency is also improved but at the same time computation cost of decoding is also increased. The reason for the latter point is that for decoding a particular symbol the embedded channel is projected onto the all modulation functions of that particular position for each set of key. It is also clear from these figures. that robustness performance for any value of M in M-ary modulation is better for M-band wavelet decomposition compared to DWT decomposition while the performance for the latter is comparatively better than spatial domain SS embedding scheme. The result is reported for JPEG 2000 compression operation, however the result is also valid for other type of signal processing operations such as linear and non linear filtering, sharpening, histogram equalization, change in dynamic range, corruption by additive noise as well as other popular lossy image compression like JPEG. Although only tested on images, there is no inherent reason why the similar results obtained and inferences made would not be applicable for one-dimensional audio signals or video sequences.

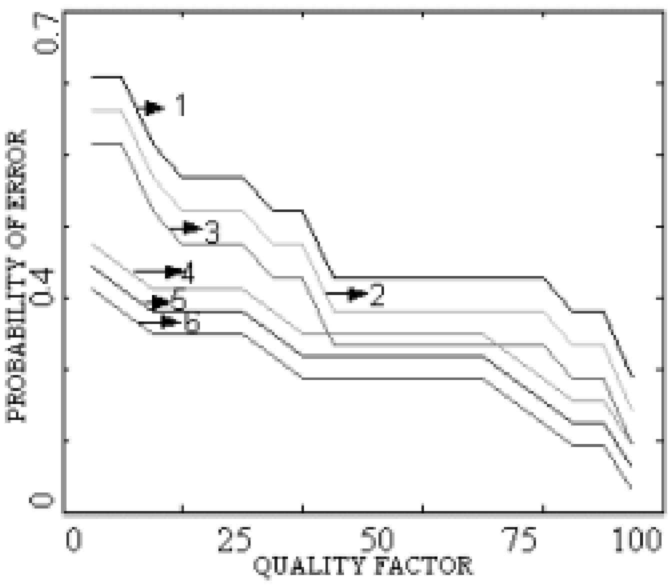

Figure 4: Robustness performance: curves 1, 2, 3 for spatial, DWT and M-band decomposition for M=8-ary modulation respectively; curves 4, 5, 6 for spatial, DWT and M-band decomposition for M=16-ary modulation respectively

6 Conclusions

The paper critically analyzes the usage of M-ary modulation principle in SS watermarking scheme.

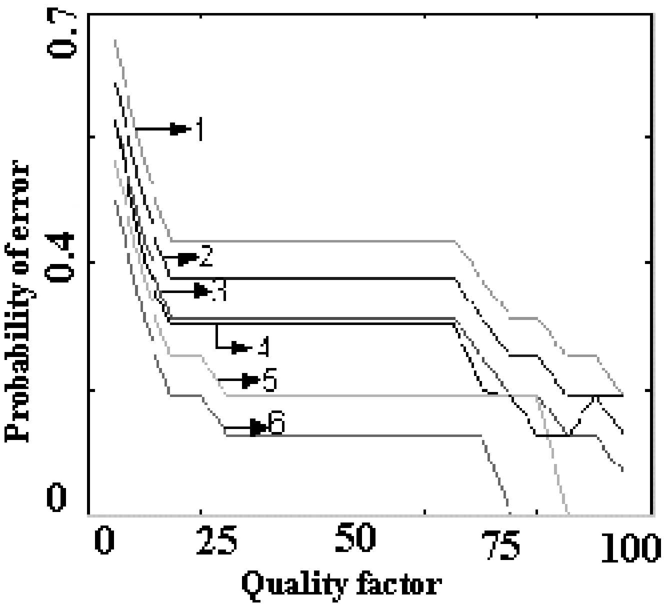

Figure 5: Robustness performance: curves 1, 2, 3 for spatial, DWT and M-band decomposition for M=32-ary modulation respectively; curves 4, 5, 6 for spatial, DWT and M-band decomposition for M=64-ary modulation respectively

It is found that in general M-ary modulation significantly improves the robustness performance of SS watermarking scheme for values of M larger than 4. However, it is quite true that large values of M result in an increased computation cost for decoding. M values larger than 256 increase computation time to a greater extent so that they become unsuitable for digital watermarking application. It is also found that for any fixed value of M, robustness performance of MbDWT is better compared to DWT scheme while the performance of the latter is again better than spatial domain approach. In watermarking applications M-ary modulation scheme is found to be more efficient for robustness improvement compared to channel coding scheme due to the problem of proper code length. This is because of the variable nature of channel distortions that depends on the size, content as well as various types of operations applied on stego data.

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