Spread Spectrum based Robust Image Watermark Authentication

T. S. Das¹, V. H. Mankan² and S. K. Sarkar³
¹Gurunanak Institute of Technology, Kolkata, ²,³Jadavpur University, Kolkata, ¹tirthasankardas@yahoo.com, ²vijaymankar@yahoo.com, ³su_sircir@yahoo.co.in

Abstract-In this paper, a new approach to Spread Spectrum (SS) watermarking technique is introduced. This problem is particularly interesting in the field of modern multimedia applications like internet when copyright protection of digital image is required. The approach exploits two-predecessor single attractor (TPSA) cellular automata (CA) suitability to work as efficient authentication function in wavelet based SS watermarking domain. The scheme is designed from the analytical study of state transition behaviour of non-group CA and the basic cryptography/encryption scheme is significantly different from the conventional SS data hiding approaches. Experimental studies confirm that the scheme is robust in terms of confidentiality, authentication, non-repudiation and integrity. The transform domain blind watermarking technique offers better visual & statistical imperceptibility and resiliency against different types of intentional & unintentional image degradations. Interleaving and interference cancellation methods are employed to improve the robustness performance significantly compared to conventional matched filter detection.

Keywords-Spread Spectrum Watermarking, Cellular Automata, Block Interleaving, Interference cancellation

I. INTRODUCTION

With the prevalence of Internet, more and more digital data can be accessed via the network. Internet users can use multimedia data without offering appropriate credits to the creators. This hinders copyright owners form sharing their work in World Wide Web. Digital watermarking technique is the solution to the copyright protection problem of digital media. This models the authentication problem as a SS digital communication problem where an auxiliary message is embedded in multimedia signals and is available wherever the later signals move. The decoded message later on serves the purpose of copyright protection, data authentication, signal tagging, broadcast monitoring, security in communication etc. The art of the digital watermarking involves the judicious selection of technological trade-offs for different factors. These include cryptographic security, psychology of perception, high data embedding rate, robustness of extraction, statistical false extraction rates and complexity. All these requirements are related in conflicting manner and the particular algorithmic development emphasizes to a greater extent on few such requirements depending on the type of applications [1-4].

The SS watermarking provides an adequate cryptographic solution to the authentication of digital media. This paper addresses the implementation of watermark-authentication algorithm on CA based architecture. The objective of the present work stems from finding out such fact that have greater impact on improvement in detection reliability and authentication of SS watermarking scheme. In our views these depend on high quality CA pattern generator having appropriate rule selector for data authenticity and security. The local neighborhood additive rules provide pseudo exhaustive generators for cryptographic security. Here, watermark authentication function based on hybrid 1-D CA is proposed.

The paper is organized as follows: Section II introduces proposed watermarking technique within CA framework for image authentication. Section III discusses about the different features of the proposed scheme. Watermarking architecture is present in Section IV. Section V shows the implementation results on 16-by-16 binary watermark and finally section VI concludes and remarks about some of the aspects analyzed in this paper.

II. PROPOSED SS WATERMARKING TECHNIQUE

Spread Spectrum watermarking is accomplished by embedding each watermark bit/symbol over many samples of the cover image using a modulated pseudo random spreading sequence. SS watermark embedding and detection are analyzed mathematically in the following subsections.

A. SS Watermark Insertion

(i) Let $B$ denotes the binary valued message bits string as a sequence of $N$ bits.

$$B = \{b_1, b_2, b_3, \ldots, b_n\}, b_i \in \{0, 1\}$$

(ii) Use the Two Predecessor Single Attractor (TPSA), Cellular Automata (CA) based scheme to perform the function of authentication of the message by the digital signature [5]. This digital signature is a function of shared secret key and message. The tags (i.e. digital signature) are mathematically represented as follows:

$$T_i = \{t_{i1}, t_{i2}, \ldots, t_{in}\}, t_{i} \in \{1, 0\}$$

(iii) $M$–ary ($M = 2^n$) modulation map is used to produce modified digital signature of $M$–ary symbols [6] and can be expressed as follows:

$$T_i' = \{t_{i1}', t_{i2}', \ldots, t_{in}'\}, t_{i} \in \{1, 0\}$$

(iv) Block interleaving discussed in section III (B) is applied over every modified tag, and the resulting interleaved sequences are determined as shown below:

$$T_i'' = \{t_{i1}'', t_{i2}'', \ldots, t_{in}''\}$$

where $T_i''$ is any one of $M$ possible number of bits per symbol ($t_{i}'')$

(v) Let $I$ denotes the image block of length $L$ i.e. image transform coefficients of length $L$, a bi–level (i.e. binary
valued) code pattern (discussed in section III) of length \( L \) is used to spread each interleaved modified tag symbol. Thus a different sets of code pattern \((U)\), each having \( H \) number of bi-level modulation functions (since total number of different symbols in interleaved modified tag is \( P \)) of length \( L \) are generated to form watermarked sequence \( W_L \).

\[
[W_L] = \frac{1}{L} \sum_{i=1}^{L} (t_i) \cdot [U] \cdot [M],
\]

where \( \alpha \) is the modulation index which optimize or trade off maximum amount of allowable distortion (robustness) and minimum watermark energy (imperceptibility/ transparency) needed for a reliable watermark detection. \( \alpha \) 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. Watermark embedding strength can be determined from structure comparison \( S(A; B) \) using cross covariance \( \sigma_{ab} \) between cover \((A)\) and watermarked image \((B)\).

\[
\sigma_{ab} = S(a,b) = \frac{1}{N-1} \sum_{i=1}^{N} (a_i - \mu_a) (b_i - \mu_b)
\]

where \( \mu_a \) and \( \mu_b \) are the mean values of the sequence \( A \) and \( B \) respectively with \( k = 1,2,3,\ldots,L \). The \( M \) th symbol will be detected at the \( i \) th position if the \( M \) th cross correlation seems to be maximum than \((M-1)\) cross correlation indices at that position. If the code pattern \((U)\) are chosen in such a way so that \( m_i((U_M)) = 0 \), the computation of \( d_i \) becomes:

\[
d_i = \langle(U_M) , I \rangle + \alpha \sum_{i=1}^{H} (t_i) ((U_M)) - m_1(I)
\]

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= \langle(U_M) , I \rangle + \alpha \sum_{i=1}^{H} (t_i) ((U_M)) - \langle(U_M) , I \rangle
\]

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

\[
(U_M)_j, j = 1,2,\ldots,L \text{ should be distinct sequences with zero average.}
\]

The spatial correlation = \( \langle(U_M)_j, (U_M)_k \rangle \) should be orthogonal.

Each \((U_M)_j\) for \( j = 1,2,\ldots,L \) should be uncorrelated with image block \( I \) when image prediction (for estimating the image distortion) is not used before evaluating the cross-correlation.

### III.WATERMARKING PRELIMINARIES

#### A.Cellular Automata

It represents the sequential behavior of a number of interconnected cells arranged in regular manner. Here, next state of each cell depends on the present state of its neighbor cells [7]. If a three neighborhood is considered, the state of each cell depends on the present state of its neighbor cells arranged in regular manner. Here, next state function for Rule 90 and Rule 150 are given below:

\[
\begin{align*}
&d_i = \langle(U_M) , I \rangle + \alpha \sum_{i=1}^{H} (t_i) ((U_M)) - m_1(I) \\
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row (or vice versa). If the linear code used is capable of correcting a single burst error of length \( t \) symbols or less in a block of length \( l \), the interleaved code will correct any single bursts of length \( \lambda l \) or less.

C. Transform for Data Hiding

It provides co-joint representation in the form of space spatial frequency resolution with local and global information of the image signal.

(1) DWT: DWT system decomposes an image signal using orthogonal filter (e.g db2) into four LL (approximation), LH (horizontal), HL (vertical) and HH (diagonal) sub-bands, thereby giving logarithmic resolution [9].

(2) M-Band WT: This system decomposes the image into \((M \times M)\) channels corresponding to different directions and resolution resulting in linear and logarithmic resolution [10].

(3) Bi-orthogonal Wavelet: In case of DWT and M-Band WT, imperceptibility and robustness performance become lower with increasing embedding rate. Interference occurs as code patterns are added to decomposed image using single scaling function. Moreover, this doesn’t yield low correlation between image and spreading sequence, therefore high robustness may not be achieved. This problem can be solved using Bi-orthogonal DWT (Bi-DWT), which provides low correlation with code patterns [11].

(4) Hilbert Transform: Similar to Bi-DWT, several authors have proposed signal processing methods that call for two wavelet transforms where one wavelet is (approximately) the Hilbert transform of the other [12]. The definition of Hilbert transform is mathematically expressed as follows: \( \Psi_h(t) \) is the Hilbert transform of \( \psi_h(t) \) if

\[
\Psi_h(\omega) = -j \psi_h(\omega), \quad \omega > 0 \\
= j \psi_h(\omega), \quad \omega < 0
\]

D. Complementary Modulation

For the random modulation techniques there are four possible types of modulations: \( MF (+, +) \), \( MF (+, -) \), \( MF (-, +) \) and \( MF (-, -) \) where \( MF \) stands for modulation function. \( MF (+/\cdot, -/\cdot+) \) represents a positive/ negative transformed coefficient modulated with a negative/ positive watermark quantity [13]. The influence of different attacks is also observed to see how they update the magnitude of transformed coefficients. These attacks can be roughly classified into two categories. The first category (like blurring, compression etc.) decreases the magnitude of most of the transformed coefficients. So, every coefficient can be modulated with \( MF (+, +) \) and \( MF (+, -) \), so that they will contribute positively to the detector response. On the other hand, second category (like sharpening, histogram equalization) tends to increase the coefficient magnitude; thereby \( MF (+, +) \) and \( MF (-, +) \) will similarly improve the detector response. On the basis of this analysis, complementary modulation strategy is presented.

The proposed scheme embeds two identical watermarks, which play complementary roles in resisting various kinds of attacks. One watermark is embedded using negative modulation rule with \( MF (+, -) \) and \( MF (-, +) \). The second watermark follows the positive modulation rule using \( MF (+, +) \) and \( MF (-, -) \).

E. Spreading Code Pattern

High detection reliability is achieved if the code pattern sequences posses very low zero lag cross-correlation among each other as well as with image block when image prediction is not used to evaluate the cross correlation. The code patterns used for SS modulation are pseudo-random or pseudo-noise (PN) sequences. These sequences can be generated by linear congruential generators. But the desired property of \( m_1[(U_{m1})_i] = 0 \) and \( (U_{m2})_i = 0 \) for \( i \neq j \) can be theoretically guaranteed only for infinite length sequence which is not feasible in practice. Optimal small set Kasami sequence can improve the detection reliability by matching Welch’s lower bound with good cross correlation properties. Gold sequence also shows good periodic cross correlation properties and also provides better detection [14]. Mayer et al. proposed deterministic sequence generation from Walsh/Hadamard basis and Gram-Schmidt orthogonalisation of PN sequences. In order to remove the deterministic nature of the basis function for authenticity, Walsh/Hadamard basis is used to modulate the spreading code patterns. This is analogous to Walsh covering in DS-CDMA digital cellular system (IS-95) by Qual Comm Inc. Gram-Schmidt orthogonalised sequence is normalized so that on an average same distortion is introduced and techniques may be fairly compared.

IV. PERFORMANCE ANALYSIS & EVALUATION

We observe the error performance of the proposed watermarking scheme. Nodes other than source and destination may also receive data and it is such that no nodes except destination node can be able to detect the original data. Hence authenticity, security and integrity of embedded data is maintained by additive neighborhood CA rules. Relative entropy distance (Kullback Leibler distance) is also used as a measure of security. Here, peak signal to noise ratio (PSNR) and structural similarity index measurement (SSIM) are used as representative objective measure of data imperceptibility. In decoder, symbol-by-symbol of hard decoding is considered assuming magnitude of interference between host signal and code pattern is much smaller than interference due to multiple symbol hiding. Mathematically the symbol error probability can be obtained as follows:

\[
P_e = (1/N)\left[ P(\epsilon / Y_{sym1}) + P(\epsilon / Y_{sym2}) + ... + P(\epsilon / Y_{symN}) \right]
\]

where \( \epsilon \) indicates the error. It is the sum of non-gaussian random variables. If the number of terms are large enough, central limit theorem may be applied and approximated by a gaussian distribution with mean (\( \mu \)) and variance (\( \sigma^2 \)) calculated as follows:

\[
X_i = \langle I_i; G_{\alpha i} \rangle = \sum \langle I_{i t} \alpha G_{\alpha i} \rangle G_{\alpha i}, \quad \mu_i = \langle 1/N \rangle \sum X_i \\
i = 1; N \quad l = 1; L
\]

\[
\sigma_i^2 = \text{var}[X_i], \quad L \text{ indicates number of signal points. The conditional distribution of detector statistics is given by:}
\]

\[
f(x_i ; \mu) \approx (1/(2\pi\sigma_i^2)^{0.5}) \exp\{(-x_i - \mu)2\sigma_i^2]\]

The robustness performance of proposed technique is evaluated for various signal processing operations e.g. linear-nonlinear filtering, JPEG & JPEG-2000 compressions etc.
over large number of benchmark images. The proposed algorithm shows greater resiliency against above stated image impairments since each symbol is embedded in two different sub bands using complimentary modulation functions. Redundancy in data hiding offers better stability for overall mean cross-correlation value and probability of error becomes low even after high degree of signal degradation. Moreover, robustness performance of Bi DWT and Hilbert transform pair of WT are much better than DWT as former decomposition offers low correlation with code patterns and higher energy content for HH sub bands compared to later decomposition. Robustness performance of M–ary modulation is better for M–Band wavelet decomposition compared to DWT with the increased value of m. Here computational cost of decoding is also increased as embedded channel is projected onto all modulation functions of that particular position for each set of key. We test the performance improvement of detection process using block interleaving along with serial and parallel interference cancellation (SIC & PIC). This improves the capacity of watermarking technique further. For SIC, decision satisfies for an embedded symbol is obtained by subtracting an estimate of already detected symbols from received signals. For PIC, decision statistics is determined for all symbols parallely in the same way until two consecutive steps are satisfied for an embedded symbol is obtained by subtracting an estimate of already detected symbols from received signals. NUMERICAL RESULTS

| Image   | Filter | SSIM  | PSNR  | Security Value |
|---------|--------|-------|-------|----------------|
| Fishing Boat | DWT/ db2 | 0.973 | 38.318 | 0.0185 |
|         | M Band | 0.985 | 40.041 | 0.0159 |
|         | Bi-DWT | 0.989 | 40.423 | 0.0160 |
|         | Hilbert Transform | 0.098 | 39.326 | 0.0162 |
| Lena    | DWT/ db2 | 0.970 | 38.367 | 0.0187 |
|         | M Band | 0.983 | 39.551 | 0.0160 |
|         | Bi-DWT | 0.987 | 39.973 | 0.0160 |
|         | Hilbert Transform | 0.976 | 39.303 | 0.0163 |

TABLE II

| QF | M = 2 | M = 4 | M = 8 | M = 16 |
|----|------|------|------|-------|
|    | P<sub>SIC</sub> | P<sub>PIC</sub> | P<sub>SIC</sub> | P<sub>PIC</sub> | P<sub>SIC</sub> | P<sub>PIC</sub> | P<sub>SIC</sub> | P<sub>PIC</sub> |
| 100 | 0.1 | 0.085 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75  | 0.3 | 0.26 | 0.1 | 0.073 | 0.1 | 0.089 | 0.057 | 0.017 |
| 50  | 0.4 | 0.38 | 0.3 | 0.262 | 0.2 | 0.179 | 0.15 | 0.103 |
| 25  | 0.5 | 0.47 | 0.4 | 0.312 | 0.3 | 0.237 | 0.3 | 0.235 |
| 0   | 0.6 | 0.53 | 0.45 | 0.353 | 0.4 | 0.320 | 0.35 | 0.317 |

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