FPGA based Implementation of Embedding and Decoding Architecture for Binary Watermark by Spread Spectrum Scheme in Spatial Domain

Sudip Ghosh, Somsubhra Talapatra, Navonil Chatterjee, Santi P Maity and Hafizur Rahaman

Abstract--- *With the increasing influence of digital network and communication, armour from perilous intrusion and corruption of information (e.g. image, video, speech etc) during transmission is a paramount issue. To protect the image and video from the unauthenticated access or tampering, watermarking is adopted as a solution. In this paper we have proposed a spatial domain Spread Spectrum (SS) watermarking scheme using binary watermark which effectively eliminates security problem while increasing robustness and enhancing perceptual quality of watermarked image. Hardware implementation of the proposed digital image watermarking algorithm using Field Programmable Gate Array (FPGA) has been accomplished.*

Keywords--- *FPGA, Binary Watermark, Spatial Domain, Spread Spectrum, Digital Image Watermarking*

I. INTRODUCTION

THE process of embedding information into a digital signal which may be used for secure communication between the sender and recipient is called Digital watermarking. The information may be embedded in the digital signal such as audio, image or video [8]. These days the use of internet has become a part and parcel in man's life. Information in form of digital images and video can be send and receive through the internet. The ever increasing efficacy of the internet and the ease of availability of sophisticated software make it possible to manipulate the digital content. Therefore the requirement for protection of digital content against unauthorized replication and modification has become the area of concern. A Digital Rights Management(DRM) technique deals with the

ownership rights of the digital content. Digital watermarking though not complete DRM mechanism can be utilized in DRM systems to prevent unauthorized access and undesirable manipulation, thereby assuring authentication[2],[3].

In Digital watermarking, information is embedded in the form of symbol, text or a number. In case of invisible watermark it must be ensured that the modification of the media, as a result of embedding information, is imperceptible. Depending on perceptibility, digital watermarking has been divided into two types- : (i) Visible Watermark (ii) Invisible Watermark [7]. Classification can also be made on the basis of whether or not any Transformation technique has been implemented, namely- (i) Spatial Domain Watermarking [1][12] (ii) Transform Domain Watermarking [5][16].

Information transmitted through perilous communication channels is prone to contamination with undesirable and pernicious data or information may be tampered. To prevent this, the concept of Pseudo random Noise sequence is widely used in the domain of image watermarking and in steganography. In order to ensure secure data communication through the insecure communication channels, it is therefore necessary to utilize some stern and effective mechanism. Spread Spectrum watermarking technique is such a mechanism where, the information is spread over a larger frequency so that during extraction the integrity of the information is not surrogated [4],[5]. Spread spectrum (SS) watermarking may be used in fragile and semi fragile watermarking by keeping the chip rate low [6]. The term chip rate indicates the number of cover signal's sample over which the watermark bit is spread [9].

The objective of this paper is to design VLSI architecture for the given image watermarking algorithm that caters to the need of media authentication as well as secure transfer of image[14][15]. Hardware implementation of digital watermarking [11] provides several advantages over its software counterpart in terms of less area requirement, low execution time, and less power consumption. In this paper, the architecture that has been created for the given watermarking algorithm, enables watermarking to be implemented instantaneously at the time of capturing the image rather than using a software procedure that calls for greater execution time. Architecture has also been developed of the proposed algorithm. Digital design of the embedding portion of the proposed algorithm using FPGA has been developed. The example of TV broadcast will highlight the significance where digital media is to be marked in real time and hardware is the

The preliminary version of this work has been appeared in the proceedings of ICACC 2012 [13].

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DOI: 10.9756/BJAIP.3096

only solution. Another example is the solution to establishing the chain of custody for forensic digital photographers [10].

The rest of the paper is organized as follows. Section II describes the proposed watermarking algorithm. Section III and IV gives the Analysis and Attacks of the proposed watermarking scheme. Section V and VI represents the VLSI architecture of the Encoder and Decoder of the proposed algorithm. Section VII depicts the Result of proposed method where the device utilization table gives the synthesis report while section VIII administers the Conclusion.

II. PROPOSED WATERMARKING ALGORITHM

The following two subsections describe different steps in watermark embedding and decoding process respectively. Here, Binary watermark is embedded directly to the pixel values of each block of the cover image using SS modulation. During decoding, watermark information is extracted using normalized correlation and the extraction of binary watermark is done using channel decoding and spatial bi-phase demodulation [13].

2.1 Watermark Embedding

The Spread spectrum (SS) watermarking using binary watermark in spatial domain is discussed in details in the following section. Different steps for watermark embedding are described as follows:

Step1: Image Partitioning

The cover image is taken as F , where $F = \{F_{ij}, 1 \leq i \leq F_{\text{length}}, 1 \leq j \leq F_{\text{width}}\}$, while $F_{ij} \in \{0, 1, \dots, 255\}$, F_{length} is the image length and F_{width} the width of image. Now we partition the cover image into $(m \times m)$ blocks which is non-overlapping, where $m = 4, 8, 16, 32$ etc. Suppose we call them as H_{ij} , where 'i' is the number of rows and 'j' is the number of columns.

Step 2: Formation of Message Vector

The message image is taken as W , where $W = \{W_{ij}, 1 \leq i \leq W_{\text{length}}, 1 \leq j \leq W_{\text{width}}\}$, while $W_{ij} \in \{0, 1\}$, W_{length} is the image length and W_{width} the width of image. We partition the watermark image into $(L \times L)$ non overlapping blocks, where $L = 2, 4, 8, 16$ etc. We call them as Q_{ij} .

Step 3: Formation of Compare Bit

The MSB plane of 2-D pixel values of H_{ij} is converted to 1-D strings. This forms the string1. Another binary string, string2 is formed using the bit values of the binary watermark image. An extended binary string is made by incorporating redundancy (repeating each bit 16 times). Now, the set of the strings formed from the cover image and the watermark image are compared with one another. If there occurs more than 50% positional match of the bits in the above form matrix, a bit '1' is assigned for the string otherwise bit '0'. Bit '1' indicates in-phase condition of two strings while out of phase condition is denoted by bit '0'.

Step 4: Generation of PN Code

We derive the vector $S_{L \times L}$ from the PN (Pseudo Noise) sequence generated from the polynomial defined for a particular image length over which the message would be embedded. $S = \{s_1, s_2, s_3, \dots, s_{L \times L}\}$, $s_i \in \{0, 1\}$. The vector Z is created by $z_i = 2s_i - 1$, where $z_i \in \{1, -1\}$. If there are equal

numbers of zeroes and ones are present in S then the vector Z will be a vector with zero mean. We have to generate 4 PN (Pseudo Noise) codes of length $(n \times n)$, where $n = 4, 8, 16$ etc.

Step 5: Watermark Embedding

We now embedded the cover image with the watermark image using the Spread Spectrum (SS) watermarking scheme. The rule is given as:

$$F^e = F + KS \quad \text{if } b_j = '0'$$

$$F^e = F - KS \quad \text{if } b_j = '1'$$

Where

F^e = Embedded image in spatial domain.

F = Cover image.

K = Modulation Index.

S = PN code.

b_j = The compare bit formed in step3 of the algorithm

The value of the modulation index is calculated through experimental result evaluation.

2.2 Watermark Image Extraction & Message Decoding

The watermark recovery process requires the sets of PN matrices (S) that were used for data embedding. Different steps for watermark decoding are described as follows:

Step 1: Image Partitioning

The received image R may be tampered with noise for which the brightness of the image can vary. The received image R is partitioned into 8×8 non overlapping blocks, suppose R^*_{ij} where, i is number of rows and j is number of column.

Step 2: Correlation Calculation

Correlation values between the watermarked image matrix and each code pattern of the set (S) are calculated. We have a total of $(M_m \cdot N_m)$ (equal to the number of watermark bits) correlation values (r_i) where $i = 1, 2, \dots, M_m \cdot N_m$.

The decision rule for the decoded watermark bit is as follows:

1. For $r_i \geq 0$, the extracted bit is 0
2. For $r_i < 0$, the extracted bit is 1.

Step 3: Substring Decoding

MSB plane of the individual blocks of watermarked image or its distorted version is picked up and a set of 1D string $P_i = \{P_1, P_2, P_3, P_4\}$ is generated from the 8×8 block. Bi-phase demodulation scheme is used in this stage. Based on the value of the extracted bit in the decoded watermark, the string either remains unchanged (if detected bit is '1') or complemented (if detected bit is '0').

Step 4: Message Decoding

Each string obtained in the above process is used to get back the binary watermark (bit redundancy). Binary detection is then applied for each substring based on the majority decision rule i.e. if more than 50% symbols are '1' in a sub substring, decision for decoding is '1', otherwise '0'. The embedded binary digits obtained from the substrings are then converted to the pixel (each pixel of watermark image is

represented by single bit) and binary watermark image is extracted.

III. ANALYSIS OF WATERMARKED IMAGE

The analysis of the watermarked image and the extracted watermark is done on the basis of the image quality and the perceptibility of the image and the amount of intrusion due to watermarking in the watermarked image. Also the error calculation of the extracted binary watermark compared to the original watermark is taken into account. Last but not the least we analyzed the variation of modulation index along with image quality.

The Structural Similarity (SSIM) index is a method for measuring the similarity between two images. The Peak Signal to Noise Ratio (PSNR) is the ratio of the maximum signal power to the corrupting noise power. The Mean Absolute Error (MAE) is a signal fidelity measure where the goal is to compare two signals by providing a quantitative score that describes the degree of similarity/ fidelity or, conversely, the level of error/distortion between them. Universal Image

Quality Index (Q) is a characteristic [21] of an image that measures the diminution or distortion of the received image to the original one. The Normalized Correlation (NC) is used to measure the similarity between two images.

Table 1: The Value of the Retrieved Watermark Image with Original Binary Watermark of the Size (64 x 64).

Value of K	PSNR	MSSIM	Q	NC	MAE
1	3.8416	0.1537	0.1602	0.1583	0.4128
5	7.5382	0.5558	0.5778	0.601	0.1762
10	11.7302	0.8086	0.8256	0.8369	0.0671
15	16.4857	0.9371	0.9381	0.9432	0.0224
20	21.3523	0.9797	0.9744	0.9814	0.0073
25	26.1236	0.991	0.9855	0.9937	0.0024
30	36.1236	0.9978	0.9946	0.9993	0.0002
1	36.1236	0.9978	0.9946	0.9993	0.0002

Figure 1: Graph Shows the Point of Intersection of PSNR of Watermark and Embedded Image. The Graph gives Optimized Value of Modulation Index (K)

Table 2: The Values of the Embedded Image with the Cover Image. Here the Cover is of Size (256 x 256)

Value of K	PSNR	MSSIM	Q	NC	MAE
1	48.1309	0.998	0.9977	0.9997	0.9999
5	34.1515	0.9552	0.9515	0.9928	4.9998
10	28.1313	0.8588	0.8581	0.9724	9.9992
15	24.61	0.7556	0.7622	0.9409	14.9975
20	22.1122	0.6609	0.6738	0.9016	19.9939
25	20.1753	0.577582	0.5948	0.8575	24.9874
30	18.5942	0.5053	0.5252	0.8115	29.9142
31	18.31	0.4921	0.5124	0.8022	30.9706

Figure 2: Graph shows that Mean Structural Similarity (MSSIM) Index Increases with Increase in Modulation Index (K)

From the above tables and graph we come to a conclusion that with the increase of the value of Modulation Index (K) the Quality of the retrieved binary watermark increases. But on the other hand if we increase K, the perceptibility of the embedded image decreases. So we have to make a trade-off between the embedded image perceptibility and the quality of the recovered image.

IV. ATTACK IMPLEMENTATION AND RECOVERY

Various types of attack have been used during implementation of the algorithm to test its robustness to measure the error from the original to the extracted watermark the above mentioned methodologies are used. The common attacks along with JPEG compression are listed below in Table 3 and 4.

Table 3: The Value of the Retrieved Watermark Image with Original Binary Watermark of the Size (64 x 64)

Attacks	PSNR	MSSIM	Q	NC	MAE
Gaussian Filter	36.124	0.999	0.998	0.9993	0.0002
Gaussian Noise	29.134	0.998	0.994	0.9968	0.0012
Salt and Pepper Noise	19.689	0.961	0.956	0.9729	0.0107
Contrast Stretching	27.093	0.991	0.998	0.995	0.0019
Sickle Noise	36.124	0.999	0.999	0.9993	0.0002
Sharpened	33.113	0.999	0.998	0.9987	0.0004

Table 4: The value of the Retrieved Watermark Image with Original Binary Watermark of the Size (64 x 64)

JPEG attack	PSNR	MSSIM	Q	NC	MAE
JPEG90	Inf	1	1	1	0
JPEG60	36.124	0.998	0.9946	0.9993	0.0002
JPEG50	36.124	0.998	0.9946	0.9993	0.0002
JPEG30	33.113	0.999	0.9986	0.9987	0.0004
JPEG20	20.326	0.973	0.9683	0.9765	0.0092
JPEG10	14.885	0.883	0.891	0.9179	0.0324

The above shown tables error implementation and the results of each. The recovery of the watermark image under the influence of the above error is quite well. Here also we can see that the modulation index plays a vital role on the amount of recovery of the original watermark image and the error intrusion in the recovered image.

Figure 3(a) show the Cover Image of Size (256 x 256); Fig 3(b) the Binary Watermark Image of Size (64 x 64); Fig 3(c) the Embedded or Watermarked Image; Fig 3(d) the Recovered Watermark Image.

V. PROPOSED VLSI ARCHITECTURE FOR ENCODER

The architecture of the proposed watermark algorithm is shown in figure below. The main building blocks are as follows: (A) Controller (B) Memory Block (i) Memory Cover (ii) Memory Watermark (iii) Memory Compare (C) Assembly and Compare Block (D) Code block.

5.1 Controller

The functionality of the controller is governed by the configuration register. The configuration register is memory mapped means that CPU can write directly to the configuration register.

Figure 4: The Embedding Architecture of the Watermarking Algorithm.

The configuration is 3bit: 1st Bit (B1) - Software Reset Bit, 2nd Bit (B2) - Preprocess Bit, 3rd Bit (B3) - Start Bit. These 3 bits are used to trigger 3 consecutive phases whose operation is described below.

In the Software reset phase internal register is reset to zero, where the reset is asynchronous. Here the images are downloaded in cover memory and watermark memory respectively. In Pre-process phase, b1, b2, b3, b4 (the four bits) set is calculated by reading (8 x 8) byte from memory cover and (2 x 2) bit are read from memory water in Consecutive cycles. 64 bit strings are formed as per the Algorithm in the Assembly and Compare block. Result is written in memory compare. In Start phase, pixels bytes are read out from Memory Cover sequentially. In this phase the embedding of the cover image is done by adding the pixel bytes with the output of the code block according to the algorithm. The embedded image is stored in the Memory Cover, which is extracted by the user after the process is completed.

5.2 Memory Block

The memory cover is $2^{16} \times 17$ bits memory which stores the cover image data of 8 bits. Next we have the memory water which is $2^{12} \times 4$ bit long. Here the watermark image is binary image which is represented by 4 bit. Lastly we have the Memory Compare which stores 4 bit compare data from the assembly and compare block. It is $2^{10} \times 4$ bit memory.

5.3 Assembly and Compare Block

A decoder is used where the select line is governed by 12 bit internal register. The two LSB bits of register are used as the select. Depending upon the register value and internal strobe each bit of watermark data is spawned 16 times and stored in water_64_out which is 6 bit long register. Now we compare the water_64_out with the cover_msb_64_dout which contains the MSB plane of the cover image (8 x 8) non

overlapping block. The two 64 bit string `water_64_out` and `cover_msb_64_dout` is compared using four comparator (C1, C2, C3, C4) 16 bit each. The output of the individual comparator is concatenated and the compare word is stored in Memory Embed.

5.4 Code Block

Code block implements $\pm (K \times S)$ as used in the proposed algorithm given in fig. 6. The code block has four PN sequence generator S1, S2, S3, S4 and with the help of b1, b2, b3, b4, it generates a value of $\pm KS$. K is a 10 bit register. MSB is the sign bit. Next bit is the integer bit and next 8 bits are for fraction. This K register is memory mapped to the external interface. $\pm S$ is a 4 bit signed value and when multiplied with K register the output generates (6+8) bit long word. The lower 8 bits are kept for fraction. If the operation is perfect, the MSB of the (6.8) is the extended sign bit. The bit next to MSB is the sign bit. These two bits should have identical values. Next four bits are for integer and last eight bits are for fraction. When this integer is added with (6.8) bit $\pm KS$, decimal points has to be adjusted for the output of the transform.

VI. PROPOSED VLSI ARCHITECTURE FOR DECODER

The decoding architecture of the proposed watermark algorithm is shown in figure 5. The main building blocks are as follows: (A) Controller (B) Linear Feedback Shift Register (C) Memory (i) Watermark Memory (ii) Memory Embed (D) Correlator.

Figure 5: The Decoding Architecture of the Watermarking Algorithm.

6.1 Controller

The controller is controls the flow of the decoder in accordance to the control word. The control word is defined by a 2 bit register. The working and functionality of the control word is defined in the table 4 which breaks the functionality into different phases. These phases are triggered by the corresponding bit pattern of the control word. In Phase1 the four LFSRs are loaded with the seed value and the PN sequence is generated. The PN sequences formed are stored in four 6 bit registers. Along with this data (embedded data) is loaded in the Memory Embed is the same phase. In the next phase B1, B2, B3, B4 (the four bits) is calculated by performing correlation between the sub-blocks and respective PN sequence. The output of the correlator is stored in the Memory Watermark. Data is extracted from the Memory Watermark through the external bus interface2 in Phase 3. The strobe signal is used for activation of the system. The

architectural diagram of the decoder gives the detail of the control signals provided by the controller.

Table 5: The control Word is given below

Control word	State of operation	Description
01	Phase I	(i)LFSR set (ii)Load data in Embed Memory
10	Phase II	(i) Decoding Operation (ii) Resultant data is stored in Watermark Memory
11	Phase III	Data read from Watermark Memory

6.2 Linear Feedback Shift Register

The LFSR will be enabled by the controller in the Phase LFSR when it sets `set_seed = '1'`. The seed is fed by the external interface by the user. The PN (Pseudo Noise sequence) is generated using the feedback mechanism. In the above stated algorithm we used PN sequence of length 64 bits. Depending on the polynomial the LFSR work in accordance to the taps to generate the PN sequence.

6.3 Memory

The Memory Embed is $2^{16} \times 17$ bits memory which stores the embedded image. Next we have the memory water which is $2^{12} \times 1$ bit long. The extracted binary watermark image data is stored in this memory.

6.4 Correlator

In this block the correlation between the embedded image and the PN sequence is calculated. The method by which the correlation is calculated as the 8×8 non-overlapping image block consisting of 64 elements is taken, each of which is multiplied with corresponding PN sequences (S1, S2, S3, and S4) which are 64 bit long. The outputs are added cumulatively and the result is divided by 64. A comparator is used to calculate whether the outputs are greater than or less than the threshold, if it greater than the extracted bit is 0 else 1. Now by using the majority logic we determine the extracted bit. If the number of '1' is more than or equal to eight then the extracted bit is '1' else '0'.

VII. RESULTS

The proposed watermarking methodology is based on the combination of channel coding and spread spectrum technique. We consider a 1 bit/pixel of size (64 x 64) and 8bits/pixel of size (256 x 256) binary images as watermark and the cover image respectively for experiment purpose. Now, the cover image is partitioned in (8 x 8) non-overlapping blocks and the watermark image is partitioned in (2 x 2) non-overlapping blocks. The partitioning of the cover i.e. (8x8) and the watermark image followed by the conversion of the integer image data to binary was done with the help of MATLAB. With the binary image data for both the partitioned cover and the partitioned watermark image, we put them in the test bench as input cover and input watermark image. The same process is repeated for the decoding process. After the extraction of the decoded watermark image, the analysis and

testing of the algorithm is done.

The synthesis of the watermark embedding have been implemented on Xilinx (ISE version 8.1) based FPGA. We have chosen Virtex series of FPGA to fit the complexities of the design. The device used is xc2vp30-7ff896 for the implementation and the language used is VHDL. The behavioral simulation was done with Synopsys VCS-MX to verify the functionality of the design. A test bench is also written in VHDL to give the input vectors for the simulated program. The estimated power for the proposed architecture is calculated using Xpower of Xilinx 8.1, which comes around 1300 mW and the frequency of operation of the system, is 82.26 MHz.

Table 6: The Synthesis Results from Xilinx ISE 8.1

Device Utilization Summary			
Logic Utilization	Used	Available	Utilization
Number of Slices	959	13696	4%
Number of Slice Flip Flops	896	27392	1%
Number of 4 input LUTs	1669	27392	4%
Number of Bonded IOBs	39	416	13%
Number of MULTS 18x18S	1	136	0%
Number of GCLKs	1	16	6%

Table 7: Shows the Results of Extracted Watermark to the Original Watermark for Test Images (256 x 256) with k=20

Table 7: The Results of Extracted Watermark to the Original Watermark for some Test Images

The Test Images	Evaluation of the Extracted Watermark to the Original Watermark					The Extracted Watermark
	PSNR	MSSIM	Quality	Normalized Correlation	Mean Absolute Error	
Airplane	27.092700	0.94663	0.948434	0.993977	0.001953
Baboon	23.819110	0.853293	0.845930	0.987345	0.004150
Barbara	26.123599	0.918701	0.913132	0.992513	0.002441
Boat	26.5812	0.92605	0.92527	0.99323	0.0022
Cameraman	33.113300	0.988550	0.993745	0.998490	0.000488
Lena	27.0927	0.95958	0.96553	0.99396	0.00195
Lighthouse	23.1133	0.91431	0.9207	0.98502	0.00488
Pepper	36.1236	0.99739	0.99904	0.99925	0.00024

Table 8, Gives comparative study of VLSI Architectures of Image Watermarking Systems Proposed in the Literature which shows our Experimental Results have improvement.

Table 8: The comparative Study of VLSI Architectures of Image Watermarking Systems Proposed in the Literature

Research Work	Design Type	Watermarking Type	Multimedia Object	Working Domain	Chip Statistics
Mohanty et. al [14],[20]	FPGA platform	Invisible	Image	Spatial	Xilinx , Virtex Series XCV50-BG256-6, 50.398MHz
Ghosh et. al [17],[18]	FPGA platform	Invisible (Binary Watermark)	Image	Transform (Walsh Hadamard Transform)	Xilinx 14.1, Virtex 4 XC4vlx200-11ff1513, Max. Frequency 90.131 MHz
Ghosh et. al [16]	FPGA platform	Invisible (Binary Watermark)	Image	Spatial and Transform (Dual mode)	Xilinx 14.1, Virtex 4 XC4vlx200-11ff1513, Max. Frequency 90.131 MHz
Maity et. al [19]	FPGA platform	Invisible	Image	Spatial bi-phase Modulation based	Xilinx,Spartan Series XCS-05 ; CLB count = 85 Max. Frequency = 80 MHz
Ghosh et. al [1]	FPGA platform	Invisible (Gray-scale Watermark)	Image	Spatial	Xilinx(ISE version 8.2i),Virtex 4 xc4vlx25-10ff676 Maximum Frequency: 219.542MHz
Ghosh et.al [12]	FPGA platform	Invisible (Gray-scale Watermark)	Image	Spatial	Xilinx, Virtex Series xc2vp30-7ff896 power consumption is 650 mw maximum frequency is 82.204 MHz.
Ghosh et.al [13]	FPGA platform	Invisible (Binary Watermark)	Image	Spatial	Xilinx (ISE version 8.1) Virtex series (xc2vp30-7ff896) Frequency of operation of the is 82.26 MHz. Estimated Power = 650 mW

VIII. CONCLUSIONS

In this paper we have proposed a spatial domain image watermarking scheme using binary watermark by combined use of channel coding and spread spectrum modulation. The algorithm is simple with low computation cost and can be easily implemented in hardware. Digital design of the proposed algorithm using FPGA has been developed and thus makes it suitable for real time authentication as well as secured communication. The analysis of the watermark image shows with the increase of the value of Modulation Index (K) the Quality of the retrieved binary watermark increases but the perceptual quality of the embedded image degrades. Hence there is a trade off between these two parameters. The VLSI architecture of the Encoder and Decoder had been implemented with Xilinx based Virtex 2pro FPGA and the observations are mentioned.

ACKNOWLEDGMENT

This work has been partially supported by the SMDP II project, DIT, MCIT, Government of India.

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