CAT-based Digital Watermarking Algorithm using the Low-Low Frequency Domain

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Abstract

Cellular automata are discrete dynamical systems, which provide the basis for the synthesis of complex emergent behavior. This paper proposes a novel algorithm of digital watermarking based on 2D Cellular Automata Transform (CAT). In this research, the carrier image is first disassembled by level-1 CAT method according to the gateway values, and then the CAT coefficients c_{kl} fall into four distinct groups. The group I is further transformed by level-1 CAT and this domain is called "low-low frequency". At last, the watermark information is embedded into this group (low-low Frequency) of the CAT coefficients c_{kl}. The experimental result shows that this proposed method is more robust against different watermarking attacks. In addition, the quality of watermarked images is also evaluated.

Keywords: *Digital Watermarking, Cellular Automata Transform, Low-low Frequency, Gateway Values.*

1. Introduction

The fast development of the internet in recent years has made it possible to easily create, copy, transmit, and distribute digital data. Consequently, this has led to a strong demand for reliable and secure copyright protection techniques for digital data.

Digital watermarking for multimedia has become one of the widely used copyright protection methods, robustness of watermarking is a key problem[1]. For the watermarking method to be effective, it should be imperceptible and robust to various image processing attacks.

In order for a digital watermarking method to be effective, it should be imperceptible, and robust to common image manipulations like compression, filtering, rotation, scaling cropping, and collusion attacks among many other digital signal processing operations[2]. Current digital image watermarking techniques can be grouped into two major classes:

1. Spatial Domain Watermarking

2. Frequency Domain Watermarking

Frequency domain technique has proved to be more effective in achieving imperceptibility and robustness. Transform domain watermarking schemes like those based on the discrete cosine transform (DCT), the discrete wavelet transform (DWT)[3], and the discrete Fourier transform (DFT). However, it is difficult for the typical schemes to know how to decide and choose the pre-determined set. For the watermark embedding in the DCT domain, if we embed the watermark in the higher frequency bands, even the watermarked image quality is considered; it is vulnerable to the low pass filtering (LPF) attack[4,5]. In contract, if we embed the watermark into the coefficients in the lower frequency bands, it should be robust against common image processing attacks such as the LPF attack. Cellular Automata (CA) technique has been applied to the transform-domain of the digital image. This advancement is very successful because the watermarking system is perceptually invisible and robust to a number of different attacks.

In this paper, we propose a novel watermarking scheme using Two Dimension Cellular Automata Transform (2D-CAT) algorithm. Different from previous schemes, our scheme bases on CAT method. First, the original image will be decomposed to a pyramid structure by CAT algorithm. The sub bands labeled LH1, HL1 and HH1represent the high frequency information. The sub band LL1 represents the low frequency information, and the low frequency LL1 is further level-1 CAT-decomposed and sorted into another four groups. Lastly, the watermark information is embedded into this area. Experiments show that our CAT-based watermarking system can improve robustness and imperceptibility. The goal of this method is to apply the 2-D CAT algorithm to enhance the robustness to different attacks in order to improve the drawbacks of the previous.

2. Image Watermarking Based On Cellular Automata Transform

2.1 One Dimension Based Cellular Automata Transform

Cellular Automata are dynamical systems in which space and time are discrete. The cells are arranged in the form of a regular lattice structure and each must have a finite number of states[6]. These states are updated synchronously according to a specified local rule of interaction. 'Wolfram' developed a set of simple rules for describing dual-state one dimensional cellular automata. For example, there are 2^3 possible configurations for each neighborhood in a dual-state, three site neighborhood automatons and 2^8 rules for the two-state/three site CA. 'Wolfram' Rule convention assigns the integer R ($R=\sum C_n 2^n$, R=0~255) to the rule generate function F, for a two state three site CA[6]. The state a_{it+1} is derived from the state of the neighborhood at t-th time level and the cellular automaton evolution is expressible in the form:

- Type 1 : $$a_{it+1} = F(a_{i-1t}, a_{i+1t}) \quad (1)$$

Here, F is the Boolean function defining the rule.

2.2 Two Dimension Based Cellular Automata Transform

Two Dimension Cellular Automata based on A_{ijkl} which is derived from one-dimensional automata:

- Type2 : $$A_{ijkl} = A_{ik} A_{jl} \quad (2)$$

- Type 8 : $$A_{ijkl} = (2a_{ik}a_{ki} - 1)(2a_{jl}a_{lj} - 1) \quad (3)$$

In this paper, we use $A_{ijkl}=A_{ik}A_{jl}$ to generate a new special form: $A_{ijkl}=(2a_{ik}a_{ki}-1)(2a_{jl}a_{lj}-1)$. The form of "3" is called Type8[7].

Table 1. Gateway Values

Gateway	Values
'Wolfram' Rule number	14
N	8
Initial configuration	11010100
Boundary configuration	cyclic
Basis function type	Type8

Table 1 shows the gateway values of 2D CAT, the coefficients for a typical orthogonal (1,-1) Type 8 basis function. The cyclic boundary conditions imposed on the end sites (i=-1and i=N) are of the form: $a_{-1k}=a_{N-1k}$, $a_{Nk}=a_{0k}$.

The basic functions A_{ijkl} (Figure1) of Dual-Coefficient transform were generated by an 8-point 'Wolfram', Rule=14 CAT basis function.

Figure1. Type 8, 2-D CAT basis function A_{ijkl}.

Figure 1 shows two-dimensional A_{ijkl} dual-coefficient basis functions, the white rectangular dots represent 1(***addition***) while the black dots are -1(***subtraction***).

We give a data f in a two dimension space which is measured by the independent discrete variables i, j. We seek a transformation in the form:

$$f_{ij} = \sum c_{kl} \times A_{ijkl} \tag{4}$$

Here k, l are vectors of nonnegative integers, c_{kl} is transform coefficient whose values are obtained from the inverse transform:

$$c_{kl} = \sum f_{ij} \times B_{ijkl} \tag{5}$$

If A_{ijkl} are orthogonal, the bases B_{ijkl} are the inverse of A_{ijkl}, the "(5)" is called Cellular Automata Transforms (CAT) and "(4)" is called Inverse Cellular Automata Transforms (ICAT)[8,9].

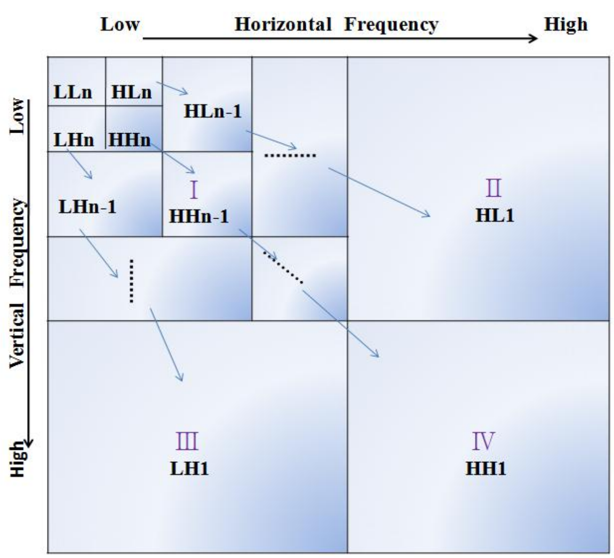

Figure2. The pyramid structure of the CA-transformed decomposition to 2-Dimension image.

Figure2 shows the CA-transformed pyramid structure. Those at even *k* and *l* locations (GroupⅠ) represent 'low frequency', located in top left of Figure2. The rest (Group Ⅱ: *k* is even and *l* is odd (top right). Group Ⅲ: *k* is odd and *l* is even (lower left). Group Ⅳ: *k* is odd and *l* is odd (lower right)) of the coefficients are 'high frequency' components[10]. The process can be repeated until final resolution level is reached. In this paper, we decompose the original images in two resolution levels (n=2) through two dimension CAT.

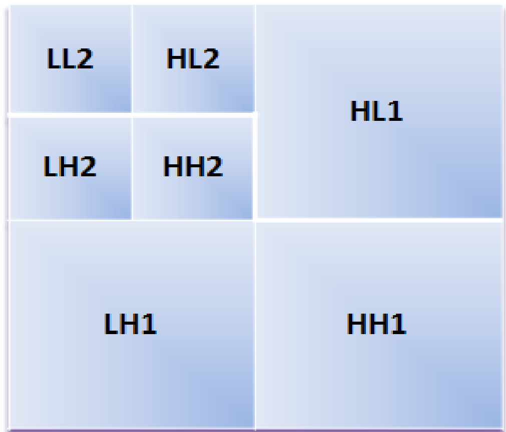

Figure3. Decomposition of CAT coefficients into four bands

Here, the LL2 domain is called "Low-Low frequency".

3. Watermarking Algorithm

3.1 Watermarking Algorithm

The watermark data embedded into 'low frequency' of CAT coefficient c_{kl}, uses the formula in the form:

$$yi = xi(1+\alpha wi) \tag{6}$$

$$yi' = ICAT(yi) \tag{7}$$

Here, *wi* is the watermark data, $xi_{\text{group I}}$ is the data of CAT coefficient c_{kl}(Low frequency), α is the embedding parameter, and *yi'* is the watermarked image information.

Watermarking extraction:

$$wi' = (yi'' - xi)/\alpha xi \tag{8}$$

Here, *wi'* is the extracted watermark data, and *yi''* is the data of CAT transform *yi'*.

3.2 Embedding Phase

The flow chart of the embedding phase is shown in Figure 4, and the details about each step will be mentioned later.

***Step*1.** Use the gateway values to obtain the CAT basis function A_{ijkl}.

***Step*2.** Decompose the original image by level-1 CAT and sort into four distinct groups. Meanwhile the GroupⅠis again subdivided into four groups by level-1 CAT which are called Low-Low frequency.

***Step*3.** Embed the watermark data into Low-Low frequency of CAT Coefficients c_{kl}.

***Step*4.** Use Level-2 2D ICAT for the 'Step3' and the watermarked image is obtained.

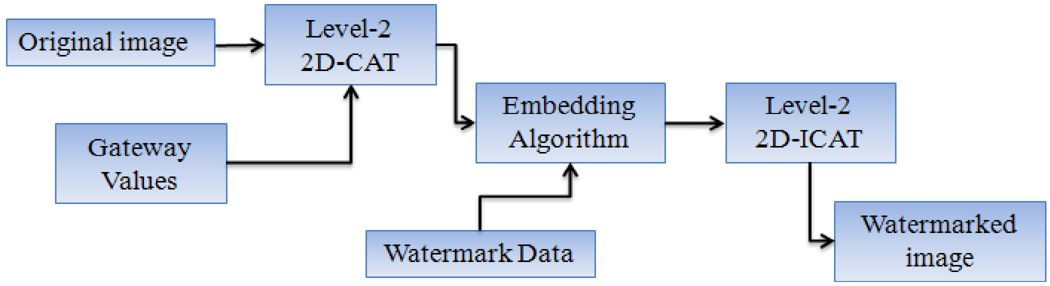

Figure4. The flow chart of cellular automata transforms algorithm.

4. Experimental Results And Analysis

4.1 Estimate Parameter

To demonstrate the performance of this scheme, we use some test images (Figure 5) (all of gray-valued, 512×512 pixels) and 'ROSE' (128×128pixel, binary-valued) as the watermark. We use the Peak Signal to Noise Ratio (*PSNR*) for evaluating the quality of the watermarked images, and Normalized Cross-Correlation (*NC*), Correlation Coefficient (*CC*) and Bit Correct Ratio (*BCR*) to judge the difference between original watermarks and extracted watermarks.

$$PSNR=10log\left(\frac{255^2}{MSE\ (W,W')}\right) \tag{9}$$

$$MSE\ (O,\ O') = \frac{1}{M\times N}\left(\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}W\text{-}W'\right) \tag{10}$$

$$BCR(O,O') = \left(1-\frac{\sum_{i=1}^{L_O} O\oplus O'}{L_O}\right)\times 100\% \tag{11}$$

$$CC(O,O') = \frac{cov\ (O,O')}{\sqrt{D\ (O)}\sqrt{D\ (O')}}\times 100\% \tag{12}$$

$$NC(O,O') = \frac{\sum\sum O\times O'}{\sqrt{\sum\sum O\times O}}\times 100\% \tag{13}$$

Here, *W* is the original image information, *W'* is watermarked image information, O and O' are the watermark and extracted watermark, and $\oplus$ denotes the Exclusive-OR operator. *M*, *N* are the sizes of images.

For testing the robustness, we compare the original watermarks with extracted watermarks. As a result, we get a higher *NC*, *BCR* and *CC* values. It means the robustness of watermark is better.

4.2 Experimental Results and Analysis

***Imperceptibility*:**

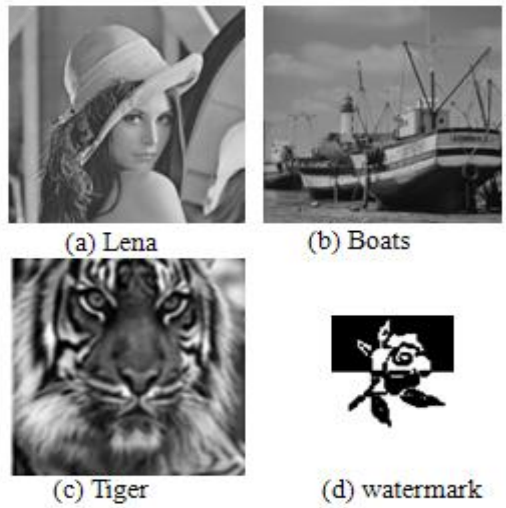

Figure5. Image (a)-(c) are original images (gray-valued, 512×512 pixels), (d) Watermark (128×128pixel,binary-valued).

We performed our proposed scheme to embed the watermark (Figure 5(d)) into test images respectively.

Table 2. PSNR, NC, CC, BCR Values

Estimate Parameters	**Watermarked images**		
	Lena	Boats	Tiger
PSNR(dB)	48.99	49.65	47.45
NC (%)	98.33	99.23	98.99
CC (%)	98.78	99.14	98.59
BCR (%)	97.11	98.97	98.21

Table 2 shows the experiment results. The PSNR values are greater, and the values of NC, CC and BCR are very high. There shows barely no difference between the original images and the watermarked images. It is clear that this watermarking method based on CAT shows good invisibility.

A comparative analysis is done between the proposed technique and other watermarking technique.

Table 3. The PSNR Values Comparison With Conventional Methods

Watermarking methods	**Lena**	**Boat**	**Tiger**
		PSNR	
DWT(**S.Joo,2011**)	38.16	33.11	31.13
DWT(**J.W.Wang,2008**)	29.83	30.08	28.66
DCT**(W.C.Chu,2003)**	36.21	35.88	39.16
CAT	44.23	42.11	48.67

In contrast, and as shown in Table 3, the difference between the PSNR values of the original algorithm (DWT, DCT) and the CAT algorithm is relatively large. This indicates that the improvement in imperceptibility can be achieved by applying CAT transform in low frequency.

***Robustness*:**

Robustness is a measure of the immunity of the watermark against attempts to tamper or degrade it, with different types of digital signal processing attacks. In this work, experiments are conducted for robustness to Gaussian Noise, compression, sharpening and cropping.

Figure 6 displays extracted watermarks while using 'Lena' as the host image. Table 4 lists PSNR values, NC values, CC values and BCR values under different attacks.

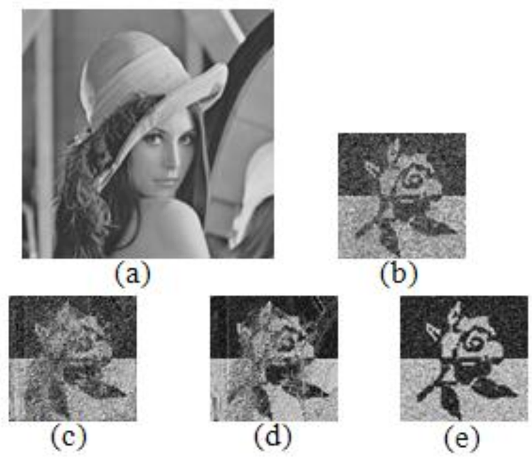

Figure 6. The extracted watermarks under different attacks

Figure 6 (a) shows the watermarked image of 'Lena' (512×512) under no attack, (b) the recovered watermark 'ROSE' (128×128) from Gaussian Noise attack. (c) the recovered watermark from JPEG compression(Q=10), (d) extracted Watermark from the sharpening attack and (e) extracted Watermark from the cropping attack(size=64×64).

Table 4. The NC, BCR, CC of The Extracted Watermark Under Various Attacks

Attacks	Watermarked images	NC(%)	BCR(%)	CC(%)
	Lena	74.34	78.31	88.32
Gaussian Noise	Boat	79.87	81.13	81.33
	Tiger	72.51	79.25	82.15
	Lena	79.24	81.09	81.43
JPEG	Boat	77.54	78.75	80.87
	Tiger	72.87	73.48	71.79
	Lena	81.25	76.69	80.45
Sharpening	Boat	78.37	81.70	63.87
	Tiger	79.76	82.75	82.64
	Lena	97.82	94.44	96.13
Cropping	Boat	98.32	96.35	95.98
	Tiger	92.75	97.95	99.14

The results of the experiment on different attacked images are shown in Fig.6 and Table 4. The extracted watermarks are recognizable. Our proposed scheme is robust to attack, such as Gaussian noise, JPEG compression, sharpening and cropping.

5. Conclusion

A new algorithm of digital watermarking system based on Cellular Automata Transform (CAT) is presented in this paper. Based on CAT method, we designed a perceptually invisible and robust watermarking system to satisfy the current requirements. Moreover, our scheme contains complexity and multiplicity about CAT theory. It is much more secure than conventional methods. The experiment results show that watermarking system based on this algorithm has achieved good robustness for common signal attacks, and has improved the invisibility of the watermarked image.

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