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Cellular Automata Transform based Invisible Digital Watermarking in Middle Domain for Gray Images

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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 new algorithm of digital watermarking based on cellular automata transform (CAT). The idea of two-dimensional CAT is introduced into the algorithm. After the original image is disassembled with 2D CAT, the watermark information is embedded into the Middle-frequency of the carrier picture. Cellular automata have a huge number of combinations, such as gateway values, rule numbers, initial configuration, boundary condition, etc. Using CAT, the robustness of the watermark will be tremendous strengthened as well as its imperceptibility. Experimental results show that this algorithm can resist some usual attacks such as compression, sharpening and so on. The proposed method is robust to different attacks and is more security.**

***Index Terms*—digital watermarking, middle-frequency, cellular automata transform, gateway values.**

I. INTRODUCTION

OWE to the popularity of internet access, the demand for embedding owner identity and other information into multimedia securely becomes very urgent, the traditional encryption algorithm for protecting the digital works has some limitations, a new information security technique-digital watermarking technology came into being in 1994, Van Schyndet, in Paper "A Digital Watermark" presented a new concept of digital watermarking. With the large number of watermarking techniques recently developed, one becomes naturally wondering if it is possible to compare the performance of different techniques in a fair manner, each watermarking scheme possesses the following attributes: invisibility, robustness. Invisibility means watermarked image should look similar to the original one, and should not suspicion by others [1]. Robustness watermarks are designed to have the ability to detect the watermark after some image processing operations, called attacks, after certain attacks and the watermark extraction process, the extracted watermarks should be highly correlated with the embedded ones. That is, the extracted watermarks need be recognizable in the robust watermarking system.

Within a few years time there are many algorithms have been proposed, these methods can be classified into two types, embedding the watermark into the spatial domain, and embedding the watermark into frequency domain. The first type provides good computing but usually degraded robustness, the second is more robust especially when the watermarking is compression methods, for watermark, if we embed the watermark in the higher frequency bands, even though the watermarked image quality is good, it is vulnerable to the low pass filtering (LPF) attack[2],[3]. Thus, embedding into the higher frequency bands coefficients is not robust, although the watermarked image quality is assured. In contrast, 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. In this paper, cellular automata (CA) technique has been applied to transform-domain of the digital image. The advancement is very successful because the constructed watermarking systems are perceptually invisible and robust to a number of different attacks.

In this paper we propose a novel watermarking scheme for the image data using two dimension cellular automata transform (CAT) algorithm, the original image will be decomposed result a pyramid structure. The sub bands labeled $LH1$, $HL1$ and $HH1$ represent the high frequency information such as edges and textures of an image. The sub band $LL1$ represents the low frequency information which contains important data [4]-[6]. In general most of the image energy is concentrated at the lower frequency sub-bands LLx and therefore embedding watermarks in these sub-bands may degrade the quality of image significantly. Embedding in the low frequency sub-bands, however, could increase robustness significantly. On the other hand, the high frequency sub-bands HHx include the edges and textures of the image and the human eye is not generally sensitive to changes in such sub-bands. However, could decrease robustness of watermark. Therefore, aside from the two observations above, in our scheme, we embed watermark into the "middle-frequency" domain of the image. The sub- band $HL1$ is decomposed again into further sub band and $HL2$ is called 'middle frequency'. The goal of our proposed method is to apply the diversity of rule and CAT algorithm complexity to enhance the robustness to different attacks, greatly

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improved the watermark security. The CAT algorithm for watermarking is a new idea, there are many problems and shortcomings need everybody to complete.

II. IMAGE WATERMARKING BASED ON CELLULAR AUTOMATA TRANSFORM

A. One Dimension Based Cellular Automata Transform

Cellular automata are dynamical systems in which space and time are discrete [7], [8]. The cells are arranged in the form of a regular lattice structure an each must have a finite number of states. 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 dimension cellular automata. There are 2^3 possible configurations for each neighborhood in a dual-state, three site neighborhood automaton, there are 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, the state a_{it+1} from the state of the neighborhood at $t-th$ time level, the cellular automaton evolution is expressible in the form:

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

Here, F is the Boolean function defined the rule.

One Dimension transform based function A_{ijkl} can be used as transform bases:

$$\text{Type1} \quad A_{ik} = \alpha + \beta a_{ik} \quad (2)$$

$$\text{Type2} \quad A_{ik} = \alpha + \beta a_{ik} a_{ki} \quad (3)$$

$$\text{Type3} \quad \begin{aligned} A_{ik} &= \rho_{ik}\rho_{ki} \\ \rho_{ik} &= a_{ik} + \beta + \rho_{ki-1} \\ \rho_{i0} &= \alpha a_{i0} + \beta \end{aligned} \quad (4)$$

$$\text{Type4} \quad \begin{aligned} A_{ik} &= \rho_{ik}\rho_{ki} \\ \rho_{ik} &= a_{ik} + \beta + \rho_{ki-1} \bmod L_W \\ \rho_{i0} &= \alpha a_{i0} + \beta \bmod L_W \end{aligned} \quad (5)$$

In which $L_W \geqslant 2$ is a integer. There are as many ways of generating Type4 bases as are the selection of L_W.

B. Two Dimension Based Cellular Automata Transform

Two dimension cellular automata based A_{ijkl} derived from one dimension based function:

$$A_{ijkl} = A_{ik} A_{jl} \quad (6)$$

Or

$$A_{ijkl} = L_w\{(a_{ik}a_{ki} + a_{jl}a_{lj}) \bmod L_w\} - (L_w - 1) \quad (7)$$

Where $L_w \geqslant 2$ is the number of state of the automaton, this paper we use $A_{ijkl}=A_{ik}A_{jl}$ generate a new special style — Type8,two dimension based function[9].

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

In this paper, the coefficients for a typical orthogonal (1,-1), the cyclic boundary conditions imposed on the end sites (i=-1and i=N) are of the forms: $a_{-1k}=a_{N-1k}$, $a_{Nk}=a_{0k}$. the CAT basis function type: Type8.

Fig. 1 shows the 2D CAT basis function image based on Type 8.

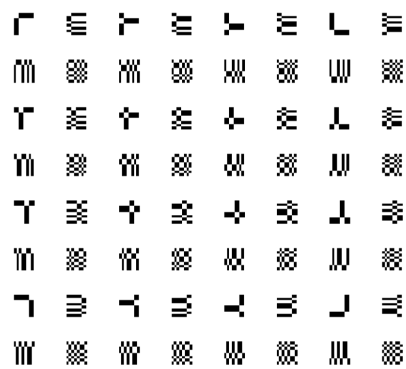


Fig. 1. Type 8 2-D CAT basis function A_{ijkl}

Give a data f in a two dimension space measured by the independent discrete variable i, j we seek a transformation in the form:

$$f_{ij} = \sum c_{kl} \times A_{ijkl} \quad (9)$$

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

$$c_{kl} = \sum f_{ij} \times B_{ijkl} \quad (10)$$

If A_{ijkl} are orthogonal, in which the bases B_{ijkl} are the inverse of A_{ijkl} ,the “(10)” called Cellular Automata Transforms (CAT) and “(9)” which we called Inverse Cellular Automata Transforms (ICAT).

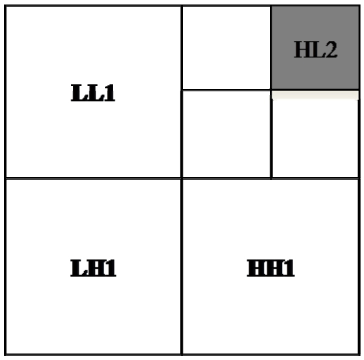


Fig. 2. The pyramid structure of the CAT-transformed decomposition to 2-D image.

Use the CAT for the original image, we can get the CAT transform coefficient c_{kl} , when k and l are even, the c_{kl} ($LL1$) represent 'low frequency', the rest ($HL1$: k even, l odd; $LH1$: k odd, l even; $HH1$: k odd, l odd) of the coefficients are 'high frequency' components. Here, $HL1$ domain is further transformed by CAT, and the $HL2$ domain is called 'middle frequency', the process can be repeated until the final resolution level is reached.

III. WATERMARKING ALGORITHM

A. Watermarking Algorithm

The watermark date is embedded into the CAT 'middle frequency' coefficient, use the multiply formula, the equation:

$$yi = xi_{HL2} \times (1 + \alpha wi) \quad (11)$$

And then use the ICAT to yi :

$$yi' = ICAT(yi) \quad (12)$$

Here, yi is the data of the watermark embedded CA transformed image, wi is the watermark data, α is the embedding parameter, yi' is the watermarked image data.

Extract watermark:

$$wi' = \frac{yi'' - xi_{HL2}}{\alpha xi_{HL2}} \quad (13)$$

Here, wi' is the extracted watermark data, yi'' is the data of CAT transformed yi' .

B. Embedding Phase

As show in Fig .3, the flow chart of the embedding phase, the details about each step will be mentioned later.

Step1. Use the Gateway values get the 2D CAT basis function A_{ijkl} .

Step2. Decompose the original image into the four groups using the 2D-CAT.

Step3. Use 2D-CAT further decompose the Group II, the 'middle-frequency' domain is obtained

Step4. Embed the watermark information into 'middle-frequency' domain.

Step5. Use inverse CAT (ICAT) transform the embedded image coefficients, the watermarked image is obtained.

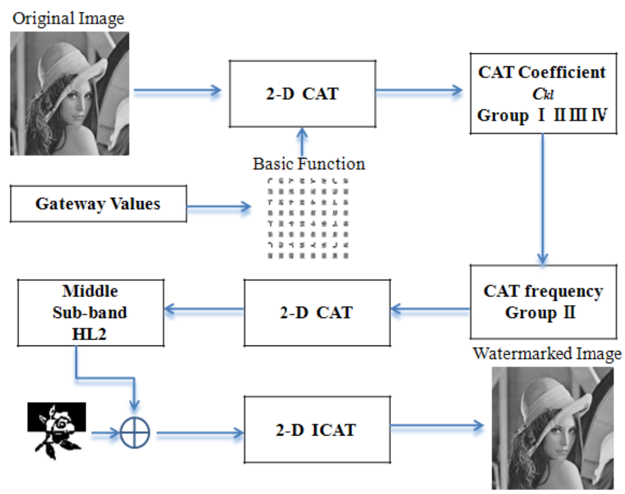


Fig. 3. The follow chart of cellular automata transforms algorithm

IV. EXPERIMENTAL RESULTS AND ANALYSIS

A. Estimate Parameters

To demonstrate the performance of the scheme, we use the test image "Lena" (gray-valued, 512×512 pixels) as the test image 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 Bit Correct Ratio (BCR) to judge the difference between embedded watermarks and extracted watermarks.

$$PSNR(O,O') \equiv 10 \times \log\left(\frac{255^2}{MSE(O,O')}\right) \quad (14)$$

$$MSE(O,O') \equiv \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (p(i,j) - p'(i,j))^2 \quad (15)$$

$$BCR(W,W') \equiv 1 - \frac{\sum_{i=1}^{L_M - 1} (wi \oplus wi')}{L_M} \qquad (16)$$

Where MSE is mean square error, $O=\{p(i,j)|0\leq i<M, 0\leq j<N\}$ and $O'=\{p'(i,j)|0\leq i<M, 0\leq j<N\}$ are the original image and the watermarked image respectively, W and W' are the watermark and extracted watermark information.

For testing the invisibility and robustness, we compare original image with watermarked image and we get a higher PSNR values, it means the invisibility is better, similarly, the robustness of watermark is better.

B. Experimental Results and Analysis

The famous image “Lena” (gray-valued, 512×512 pixels) as the test image in this scheme, and “ROSE” (128×128 pixels, binary-valued) as the watermark.

(a) (b)

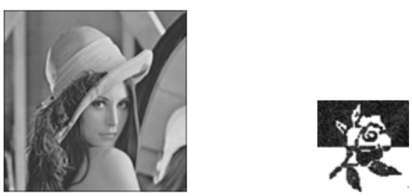
Fig. 4. (a)Original image “Lena” (b) Watermark.

TABLE I
PSNR VALUES UNDER DIFFERENT METHODS

PSNR values(dB)			
2D CAT method		DWT	DCT
Rule=43	Rule=14	(Wang,2008)	(Chu,2004)
59.78	41.29	33.25	39.21

Here, TABLE I shows PSNR values of CAT are higher than original methods, it is clear that this algorithm based on CAT shows good invisibility.

In order to test the robustness of the proposed scheme, we first attack the watermarked image and then extract the watermark, the possible attacks include scaling, Gaussian noise, JPEG compression, rotating and cropping attack.



(a) (b)

Fig. 5. (a) Scaling Attack (Factor=0.8), (b) Extracted Watermark.

(a) (b)

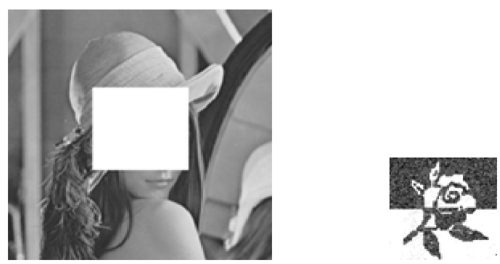
Fig. 6. (a) Gaussian Noise (Factor=0.1), (b) Extracted Watermark.

(a) (b)

Fig. 7. (a) Reconstructed image from JPEG Compression (Factor=0.1), (b) Extracted Watermark.

(a) (b)

Fig. 8. (a) Rotating attack (angle=Pi/20), (b) Extracted Watermark.



(a) (b)

Fig. 9. (a) Cropping Image, (b) Extracted Watermark.

In this work, a comparative analysis is performed between our proposed method and existing watermarking methods (J.W. Wang, G. Liu, etc.2008 discrete wavelet transform (DWT), W. C. Chu. 2003 discrete cosine transform (DCT)).

TABLE II
WATERMARKED IMAGE UNDER SCALING ATTACK

Bit Correct Ratio Values			
scaling (Factor)	CAT Rule=43	DWT (Wang,2008)	DCT (Chu,2004)
0.2	0.71	0.62	0.47
0.4	0.78	0.70	0.62
0.8	0.89	0.81	0.71
1	1	0.99	0.98
1.1	0.96	0.90	0.87
1.5	0.84	0.73	0.78
2	0.62	0.46	0.39

From the experiment results, TABLE II shows the BCR values of the proposed method are greater than DWT and DCT watermarking methods, and the extracted watermark is visible, it is clear that CAT method shows good robustness.

TABLE III
WATERMARKED IMAGE UNDER JPEG ATTACK

Bit Correct Ratio Values			
JPEG (Quality)	CAT Rule=43	DWT (Wang,2008)	DCT (Chu,2004)
0.9	1	0.89	0.91
0.8	0.98	0.86	0.84
0.7	0.92	0.80	0.80
0.6	0.84	0.81	0.71
0.5	0.79	0.80	0.62
0.3	0.71	0.63	0.56
0.2	0.69	0.65	0.51
0.1	0.66	0.69	0.50

TABLE III shows the BCR values of the proposed method which compares with original methods under the JPEG compression attack. The compressed factor values 0.1 to 0.9.

TABLE IV
WATERMARKED IMAGE UNDER ROTATING ATTACK

Bit Correct Ratio Values			
Angle degree	CAT Rule=43	DWT (J.W.Wang,2008)	DCT (W.C.Chu,2004)
-10	0.90	0.83	0.73
-5	0.98	0.81	0.79
0	1	0.82	0.81
5	0.97	0.85	0.72
15	0.87	0.74	0.75
30	0.74	0.69	0.54
40	0.62	0.48	0.41

TABLE IV shows the BCR values of different methods under rotating attack.

TABLE V
WATERMARKED IMAGE UNDER CROPPING ATTACK

Bit Correct Ratio Values			
cropping (size)	CAT Rule=43	DWT (Wang,2008)	DCT (Chu,2004)
16×16	0.98	0.83	0.77
32×32	0.90	0.83	0.82
64×64	0.88	0.73	0.71
160×160	0.76	0.60	0.68
256×256	0.65	0.42	0.55

TABLE V shows the BCR values of different methods under cropping attack. The result of the experiment on different attacks are show on Fig.5 to Fig.9 and TABLE II to TABLE V, the extracted watermarks of our proposed method are recognizable. Our proposed scheme is robust to attacks, such as scaling, Gaussian noise, JPEG compression, rotating and cropping attack.

V. CONCLUSIONS

A new algorithm of digital watermarking based on cellular automata transform (CAT) is presented in this paper, which mainly introduces that we use the two dimensions CAT algorithm: gateway, a certain rule, initial configuration and boundary configuration which carrier image is transformed by 2D-CAT and ICAT. Experiments show that watermarking according to our algorithm has good robust for common signal processing, noise disturb and some hostility assaults.

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