Robust Digital Watermarking in CAT Two Bands

Xiao-Wei Li, Jae-Sik Yun, Sung-Jin Cho, and Seok-Tae Kim

***Abstract*—In recent years, many digital watermarking techniques have been proposed to protect the copyright of digital multimedia data. This paper proposes a novel and robust algorithm of digital watermarking based on cellular automata transform (CAT). The idea of two-dimensional CAT is introduced in the algorithm. After the original image is disassembled by level-3 CAT, the watermark data is embedded into the two bands (LL3 and HH3) of the carrier image. Cellular automata have multiple gateway values, such as rule numbers, initial configuration, boundary condition. Using CAT algorithm, the robustness of the watermark as well as the imperceptibility will be strengthened. Experimental results show that the algorithm can resist some usual attacks such as compression, sharpening. This proposed method is robust to different attacks.**

***Index Terms*—Digital watermarking, intentional attacks, two-dimensional CAT.**

I. Introduction

With the redundancy of the medium as image and voice, digital watermarking technology is to use the digital embedding method to hide the watermarking information into the digital products of image and video. The new technology of digital watermarking has been advocated by many specialists as the best solution for such multimedia copyright protection problems [1]. It is expected that digital watermarking will have a wide-span of practical applications such as digital cameras, medical imaging, image databases, and video-on-demand systems, along with many others.

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

Compared to spatial domain techniques, frequency-domain watermarking techniques proved to be more effective with respect to achieving the imperceptibility and robustness requirements of digital watermarking algorithms.

Cellular Automata are dynamical systems in which space and time are discrete [3], [4]. A cellular automaton can be thought of as a stylized universe. Space is represented by a uniform grid, with each cell containing a few bits of data [5]. Time advances in discrete steps and the laws of the 'universe' are expressed in a small look-up table where each cell computes its new state from that of its close neighbors. Thus, the systems' laws are local and uniform. All cells on the lattice are updated synchronously [6].

In this paper, we propose a robust watermarking scheme for the image data using two dimension cellular automata transform (CAT) algorithm. The transform results in a decomposed pyramid structure of the original image. The sub bands labeled LH, HL and HH represent the high frequency information such as edges and textures of an image. The sub band LL represents the low frequency information which contains important data [7].Most traditional CAT methods were achieved by using the single CAT rule or by only embedding the watermark information in the low frequency of the original image. Unlike other CAT methods, we embedded the watermark in the LL3 and HH3 sub bands in this research. We also compared the different CAT rules and selected six of different rules for this work. The goals of our proposed method are to apply the diversity of rule and CAT algorithm complexity to enhance the robustness of the watermark and greatly improve the security of the watermarked images. However, watermarking based on CAT algorithm is a new idea; therefore, many technical problems and shortcomings are yet to be solved.

II. 2-D Cellular Automata Transform

As the name suggests, the basic element of CAT is a cell. A cell is a kind of memory element and stores one or more attributes each of which has two or more states [8], [9]. These states are updated synchronously according to a specified local rule of interaction. In the simplest situations, each cell can have binary states 0 or 1. CA transforms can be utilized in the way other transforms (e.g., Fourier, Laplace, wavelets, etc.) are utilized. Cellular automata are capable of generating billions of orthogonal, semi-orthogonal, bi-orthogonal and non-orthogonal bases.

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 function "(1)":

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

Here, F is the Boolean function which is defined by the rule.

In a 1-D space our goal is to generate the transform basis function $A = A_{ik}$, a few basis types including the following types:

Type 1:

Manuscript received August 7, 2012; revised October 1, 2012.

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

Here, a_{ik} is the state of the CA at the node i at time $t=k$ while α and β are constants.

Type 2:

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

Two dimension Cellular Automata based A_{ijkl} derived from one dimension based function "(4)":

$$A_{ijkl} = A_{ik} A_{jl} \quad (4)$$

Fig. 1. The generation process of 2D cat function A_{ijkl}

There are as many canonical 2-D bases as permutations of 1-D base [10], [11].

One interesting 2-D basis function is derived from the evolving one-dimensional automata as:

$$A_{ijkl} = L_W\{(a_{ik}a_{ki} + a_{jl}a_{lj}) \bmod L_W\} - (L_W - 1) \quad (5)$$

where $L_w \geq 2$ is the number of state of the automaton. In this paper, we use Type2: $A_{ijkl}=A_{ik}A_{jl}$.

TABLE I: GATEWAY VALUES

Gateway	Values
Wolfram Rule number	···143···
N	8
Initial configuration	01011101
Boundary configuration	Cyclic
Basis function type	Type 2 : $A_{ik} = 2a_{ik}a_{ki} - 1$

In this paper, we use Table I, basis function Type 2, given α=-1, β=2 .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: $a_{-1k}=a_{N-1k}$, $a_{Nk}=a_{0k}$.

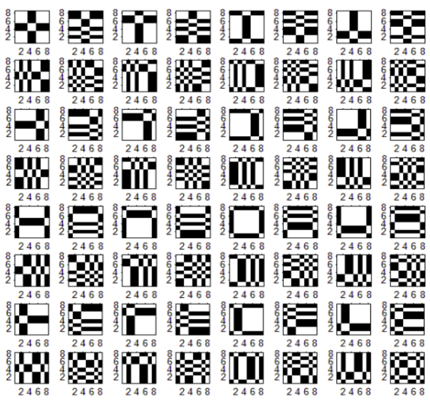


Fig. 2. 2D CAT basis function A_{ijkl}. Rule=143.

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

$$f_{ij} = \sum c_{kl} \times A_{ijkl} \quad (6)$$

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

$$c_{kl} = \sum f_{ij} \times B_{ijkl} \quad (7)$$

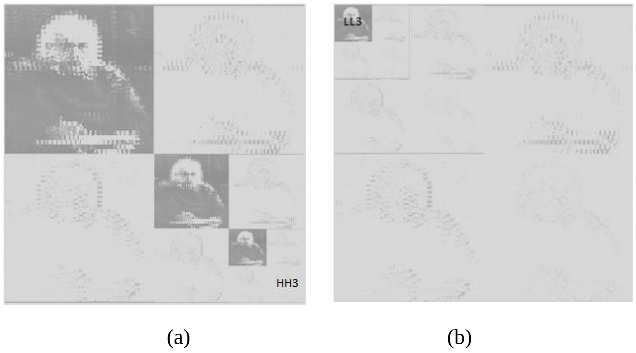


Fig. 3. Decomposition of cat coefficients in three resolution levels through level-3 cat.

As shown in Fig. 3, sub band LL3 is equivalent to the "low-low-low" frequency components. HH3 sub band is "high-high-high" frequency components.

III. THE ANALYSIS OF WATERMARKING ALGORITHM

A. Watermark algorithm

The watermark data imbedded into the CAT low frequency coefficient gives the following function "(8)":

$$O' = O + \alpha W \quad (8)$$

Then we use inverse CAT (ICAT) to transform O':

$$O'' = ICAT(O') \quad (9)$$

Here, O is the data of CAT transformed image, W is the watermark data, α is the Embedding parameter and O'' is the watermarked image data.

B. Embedding Phase

As shown in Fig. 4, the flow chart of the embedding phase, the details about each step will be mentioned later.

Step1. Use the CA Gateway values to get the 2D CAT base function A_{ijkl}.

Step2. Decompose the original image into the frequency domain LL1, LH1, HL1 and HH1 using the level-1 CAT.

Step3. Transform the sub bands LL1 and HH1 using level-2 CAT and get low-low-low frequency LL3 and high-high-high frequency HH3.

Step4. Embed the watermark information in CAT frequency LL3 and frequency HH3.

Step5. Apply the inverse CAT to obtain the watermarked image.

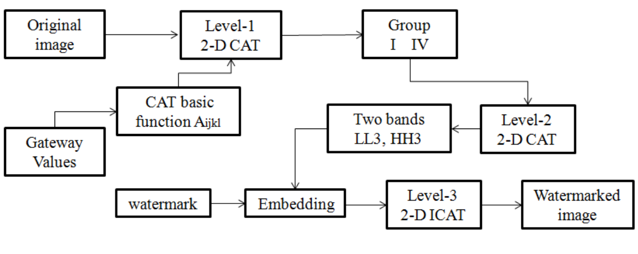


Fig. 4. The flow chart of cellular automata transforms algorithm

IV. Experimental Results and Analysis

A. Estimate Parameters

To demonstrate the performance of the scheme, we use the image "Einstein" (gray-valued, 1024×1024 pixels) as test image and "ROSE" (128×128pixels, binary-valued) as the watermark. We use the Peak Signal to Noise Ratio (PSNR) [12] for evaluating the quality of the watermarked image and Bit Correct Ratio (BCR) to judge the difference between the watermarked images and the original image.

$$PSNR \equiv 10 \times log(\frac{255^2}{MSE(W,W')}) \quad (10)$$

$$MSE(W,W') \equiv \frac{1}{M \times N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}(W-W')^2 \quad (11)$$

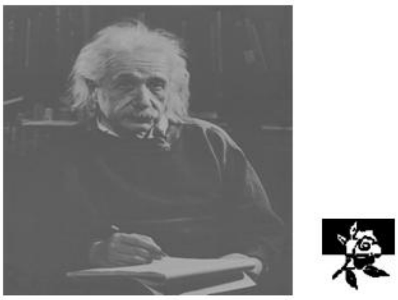
$$BCR \equiv (1-\frac{\sum_{i=1}^{L_M}(w_i \oplus w_i')}{L_M}) \times 100\% \quad (12)$$

Here, *W* and *W'* are the original image and watermarked image respectively, w_i and w_i' are the original watermark and extracted watermark.

B. Experimental Results and Analysis

The test image "Einstein" and the watermark logo "ROSE" are used in the experiment. The various CAT rules used for testing were rule1=14, rule2=15, rule3=43, rule5=159, rule4=11, rule5=143 (Fig. 2) and rule6 =158. The watermarked image "Einstein" is subjected to attack like JPEG compression, cropping, rotation and scaling.

Fig. 5 shows the result of the proposed technique without any attack. The extracted cover image and sign have good PSNR and the watermark is imperceptible in the watermarked image.



(a) (b)

Fig. 5. Rule=143 CAT-based watermarked image, (a) watermarked image "Einstein" (gray-valued, 1024×1024 pixels) and (d) extracted watermark (128×128 pixels, binary-valued).

The PSNR values of watermarked image using sub bands LL1 and HH1 are shown in Table II with different CAT rules.

TABLE II: PSNR Values of Watermarked Image with CAT Rules

PSNR Values (dB)						
	Rule1	Rule2	Rule3	Rule4	Rule5	Rule6
CAT(LL3)	58.32	38.54	52.16	28.37	72.89	33.21
CAT(HH3)	59.24	39.21	56.32	30.24	76.84	35.80

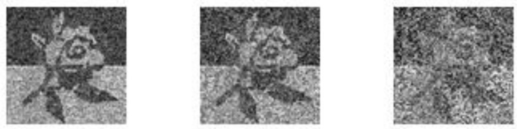
A comparative analysis is done between the proposed technique and a DWT (M. D. Hsieh, Tseng and Y. Huang, 2001) watermarking technique. Comparison of the Bit correct ratio values of the watermarks which are extracted from the attacked watermarked images is done for various attacks as shown in Fig. 6 to Fig. 9.

(a) (b) (c)

Fig. 6. Extracted watermarks under Rotation (angle=30) attack, (a) CAT-LL3, (b) CAT-HH3, (c) DWT-domain

(a) (b) (c)

Fig. 7. Extracted watermarks under JPEG compression attack (Q=0.3), (a) CAT-LL3, (b) CAT-HH3, (c) DWT-domain



(a) (b) (c)

Fig. 8. Extracted watermarks under Scaling attack (scaling factor=0.4), (a) CAT-LL3, (b) CAT-HH3, (c) DWT-domain

(a) (b) (c)

Fig. 9. Extracted watermarks under Cropping attack (size=32x32), (a) CAT-LL3, (b) CAT-HH3, (c) DWT-domain

TABLE III: Watermarked Image Under Rotating Attack

Bit Correct Ratio Values			
	CAT- based		DWT-based
Angle (degree)	LL3 sub band	HH3sub band	DWT domain
-10	0.91	0.83	0.69
-5	0.97	0.95	0.88
0	1	1	0.98
5	0.93	0.91	0.87
15	0.95	0.80	0.67
30	0.92	0.73	0.60
40	0.84	0.56	0.52

TABLE IV: Watermarked Image Under Jpeg Compression Attack

Bit Correct Ratio Values			
	CAT- based		DWT-based
JPEG(Quality)	LL3 sub band	HH3sub band	DWT domain
0.1	0.83	0.65	0.53
0.2	0.86	0.71	0.61
0.3	0.96	0.89	0.63
0.4	0.95	0.87	0.67
0.5	0.94	0.86	0.79
0.6	0.97	0.90	0.82
0.7	0.99	0.96	0.84
0.8	0.99	0.95	0.84
0.9	1	0.93	0.91

TABLE V: WATERMARKED IMAGE UNDER SCALING ATTACK

Bit Correct Ratio Values			
	CAT- based		DWT-based
Scaling(factor)	LL3 sub band	HH3sub band	DWT domain
0.2	0.65	0.59	0.37
0.4	0.79	0.65	0.41
0.8	0.83	0.78	0.42
1	1	0.99	0.91
1.1	0.99	0.92	0.73
1.3	0.91	0.80	0.58
1.5	0.81	0.63	0.36

TABLE VI: WATERMARKED IMAGE UNDER CROPPING ATTACK

Bit Correct Ratio Values			
	CAT- based		DWT-based
Cropping(size)	LL3 sub band	HH3sub band	DWT domain
16×16	0.97	0.99	0.78
32×32	0.96	0.98	0.63
64×64	0.87	0.89	0.68
128×128	0.82	0.81	0.54
160×160	0.79	0.71	0.53
200×200	0.66	0.53	0.49

From the experiment results shown in the figures and tables above (Fig. 6 to Fig. 9, Table III to Table VI), we can see that the BCR values under the cropping attack for embedded watermark in the sub bands LL3 and HH3 are similar. However, BCR values for sub band HH3 are smaller than those of LL3 after rotating JPEG compression and scaling attacks. Moreover, watermark embedding in LL3 sub band is more robust against other attacks. Comparing our proposed method and DWT-based method, we may conclude that the CAT-based method is more robust under various attacks.

V. CONCLUSION

In this paper, a new algorithm of digital watermarking based on level-3 2-D cellular automata transform (CAT) is presented. It mainly introduces that we use the two dimensions CAT algorithm: gateway, a certain Rule, initial Configuration and Boundary Configuration which carrier image was transformed by level-3 CAT and level-3 ICAT. Experiments show that watermarking according to our algorithm has good robustness for common signal processing, noise disturb and some hostility assaults.

Our experimental results provide satisfactory data compared with most recent works in this field. In our future work, we plan to investigate the possibility of embedding encrypted watermarks in more exact and rational sub bands of high levels of CAT to provide more accurate forgery detection.

REFERENCES

[1]. M. D. Hsieh, Tseng, and Y. Huang, "Hiding digital watermarks using multi-resolution wavelet transform," *IEEE Trans. on Industrial Electronics*, vol. 48, pp. 875-882, 2001.
[2]. S. Joo, Y. Suh, J. Shin, H. Kikuchi, and S. J. Cho, "A new robust watermark embedding into wavelet DC components," *ETRI Journal*, vol. 24, no. 5, pp. 401-404, 2002.
[3]. P. L. Rosin, "Training cellular automata for image processing," *LNCS*, vol. 3540, pp. 195-204, 2005.
[4]. R. Shiba, S. Kang, and Y. Aoki, "An image watermarking technique using CAT," *2004 IEEE Region 10 Conference*, vol. 1, pp. 303-306, 2004.
[5]. D. P. Mukherjee, S. Maitra, and S. T. Acton, "Spatial domain digital watermarking of multimedia objects for buyer authentication," *IEEE Transactions on Multimedia*, vol. 6, no. 1, pp. 1-15, Feb. 2004.
[6]. B. Viher, A. Dobnikar, and D. Zazula, "CA and follicle recognition problem and possibilities of using ca for image recognition purposes," *International Journal of Medical Informatics*, vol. 49, pp. 231-241, 1998.
[7]. W. C. Chu, "DCT-based image watermarking using sub-sampling," *IEEE Trans. on Multi-Media*, vol. 1, pp. 34-38, 2003.
[8]. S. J. Cho, U. S. Choi, H. D. Kim, and Y. H. Hwang, "Analysis of complemented CA derived from linear hybrid group CA," *Computers and Mathematics with Applications*, vol. 53, no. 1, pp. 54-63, 2007.
[9]. C. L. Chang, Y. J. Zhang, and Y. Y. Gdong, "CA for edge detection of images," *IEEE International Conference on Machine Learning and Cybernetics*, Shanghai, 2004, pp. 3830-3834.
[10]. A. Badr, "An alternative CA cryptogram", *Studies in Informatics and Control*, vol. 11, pp. 339-347, 2002.
[11]. S. T. Kim and Y. R. Piao, "Robust and secure inim-based 3D watermarking scheme using cellular automata transform," *IJMICS*, pp. 1767-1778, 2009.
[12]. Y. R. Piao and S. T. Kim, "Two-dimensional cellular automata tranform for a novel edge detection," *Computability in Europe 2008 Logic and Theory of Algorithms*, Greece, June 16-20, 2008.

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