# 2-D CAT-Based Medical Image Watermarking Algorithm

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

***Abstract*—Digital watermarking has been proposed to increase medical image security, confidentiality and integrity. This paper proposes a secure watermarking system using Arnold scrambling and 2-D Cellular Automata Transform (CAT). In the first step, the original image is decomposed into two levels by CAT transform. Then the watermark is scrambled using Arnold's scrambling algorithm and decomposed into one level by CAT transform. At last, the LL, HL, LH and HH sub bands of the watermark are embedded into the 'low-low frequency' and 'middle frequency' of the original image respectively. This algorithm is tested on medical images "BODY" and "VESSEL" (512x512, gray scale) with binary watermark of size 256x256. Experiment results show that our CAT-based watermarking system can simultaneously improve security, robustness and image quality of the watermarked image.**

***Index Terms*—Arnold scrambling, cellular automata transform, digital watermarking.**

## I. Introduction

Watermarking has become an important issue in medical image security, confidentiality and integrity [1]. Medical image watermarks are used to authenticate (trace the origin of an image) and/or investigate the integrity (detect whether changes have been made) of medical images. One of the key problems with medical image watermarking is that medical images have special requirements. A hard requirement is that the image may not undergo any degradation that will affect the reading of images. Generally, images are required to remain intact to achieve this, with no visible alteration to their original form [2], [3].

For the watermarking method to be effective, it should be imperceptible and robust to various image processing attacks. Current digital image watermarking techniques can be grouped into two major classes: frequency-domain and spatial-domain techniques. Frequency domain techniques have been proved to be more effective in achieving imperceptibility and robustness. Typical schemes were based on transform domain techniques which are discrete cosine transform (DCT), Discrete Wavelet Transform (DWT) and Discrete Fourier Transform (DFT). However, a disadvantage for this scheme is 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 though the watermarked image quality is considered, it is vulnerable to the Low Pass Filtering (LPF) attack. In contrast, if we embed the watermark in the lower frequency bands, it should robust against common image processing attacks such as the LPF attack. However, embedding the lower frequency bands will cause the watermarked image quality to greatly degrade to compare with the original image. This comes from the fact that the energies of most nature images are concentrated in lower frequency bands and the human eyes are more sensitive to the noise caused by modifying the lower frequency coefficients. Therefore, aside from the two observations above, in this work, we claim to embed the watermarks into 'middle-frequency' bands.

Von Neumann conceived the first CA in the late forties. (Von Neumann's work on self-reproducing automata was completed and described by Arthur Burks) [4]. Cellular automata are discrete dynamical systems whose behaviors are completely specified in terms of a local relation. All cells on the lattice are updated synchronously. In this paper, we propose a secure watermarking scheme using Arnold Scrambling and two dimension cellular automata transform (CAT) [5], [6] algorithms. Different from previous schemes, our scheme bases on CAT. Initially, the original image will be decomposed into 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 and LL1 represent the low frequency information which contains important data. The sub band LL1 is decomposed again into further sub bands LL2, HL2, LH2 and HH2. Then the watermark is scrambled using Arnold's scrambling algorithm and decomposed into level-1 by CAT transform. At last, the sub bands of the watermark are embedded into the "middle frequency" and "low-low frequency" of the original image. The experiment shows that our CAT-based watermarking system can simultaneously improve security, robustness and quality of the watermarked image.

## II. Algorithm of CAT

Cellular Automata are dynamical systems in which space and time are discrete. A CA is a collection of $n$ storage elements. The elements are called the cells which take on discrete values [7]-[10]. One-dimensional cellular spaces offer the simplest environment for generating CAT bases. They offer several advantages including: (i) the possibility of generating higher-dimensional bases from combinations of the one dimensional bases and (ii) The excellent knowledge base of one-dimensional cellular automata. In our work, two Dimension Cellular Automata basis function $A_{ijkl}$ is derived from one-dimensional automata:

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$$A_{ijkl} = A_{ik} A_{jl} \quad (1)$$

Here, $A_{ik}$ is the CAT 1-D based function, $A_{ik}$= (2a$_{ik}$-1) × (2a$_{ki}$-1).

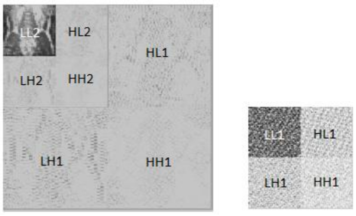
In a two dimension space, an image data $f$ is measured by the independent discrete variable $i$, $j$. We seek a transformation in the equation “(2)”:

$$f_{ij} = \sum c_{kl} \times A_{ijkl} \quad (2)$$

Here, $k$ and $l$ are vectors of nonnegative integers, $c_{kl}$ is transform coefficient whose value is obtained from the inverse transform equation “(3)”:

$$c_{kl} = \sum f_{ij} \times B_{ijkl} \quad (3)$$

If $A_{ijkl}$ are orthogonal, the bases $B_{ijkl}$ are the inverse of $A_{ijkl}$, the equation “(3)” is called Cellular Automata Transforms (CAT) and the equation “(2)” is called Inverse Cellular Automata Transforms (ICAT) [11], [12].




(a) (b)

Fig. 1. (a) The level-2 pyramid structure of “BODY”, (b) the level-1 pyramid structure of Arnold scrambled watermark “PK”.

The pyramid structure is shown in Fig. 1. The sub band LL2 is called ‘Low-Low frequency’ and the sub bands labelled LH2, HL2 and HH2 are called ‘middle frequency’ of the original image.

## III. Arnold Scrambling Algorithm

The watermark in this work is scrambled in order to guarantee the embedded watermark against clipping and re-sampling and to improve its robustness. In this work, Arnold transform is chosen as pretreatment method for watermark signal as it is simple and periodic. For a digital square image, discrete Arnold mapping can be done as the equation “(4)”:

$$[x \quad y] = [x + y \quad x + 2y] \bmod t \quad (4)$$

Here, “$t$” is the width (height) of the watermark. Every pixel in the image is transformed using the above formula. After traversing all of pixels in the image, a scrambled image will be gained. Transforming an image repeatedly can generate different results until reaching the requirement. Due to the Arnold transform periodicity, the original image can be recovered. Fig. 2 shows the result of watermark “PK” after Arnold scrambling algorithm.

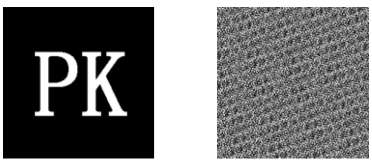



Fig. 2. The Arnold scrambled watermark.

## IV. Watermarking Algorithms

### A. Watermarking Algorithms

Watermark is embedded using the following equations “(5)” and “(6)”:

$$O' = O \times (1 + \alpha W) \quad (5)$$

$$O'' = Level - 2ICAT(O') \quad (6)$$

Here, $W$ is the watermark data, $O$ is the information of level-2 CAT coefficient $c_{kl}$, $\alpha$ is the embedding parameter and $O''$ is the watermarked image data.

### B. Embedding Phase

The flow chart of the embedding phase is shown in Fig .3. The details about each step will be mentioned later.

Step1. Apply level-2 CAT to decompose original image into four non-overlapping multi-resolution sub bands.

Step2. Apply level-1 CAT to the scrambling watermark to get four smaller sub bands.

Step3. Embed the sub bands of the watermark into the ‘low-low’ and ‘middle frequency’ of the CAT coefficient.

Step4. Obtain the watermarked image using the level-2 ICAT for Step 3.

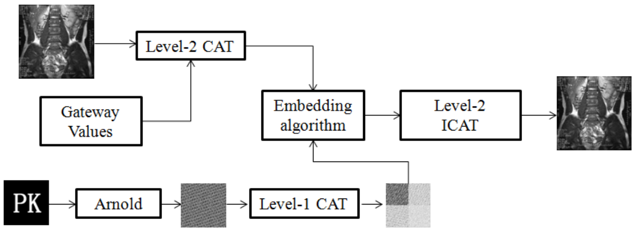



Fig. 3. The flow chart of cellular automata transforms algorithm.

## V. Analysis Of Performance

The proposed CAT image watermarking algorithm is evaluated on the performance using the 512x512 cover images “BODY” and “VESSEL” and the binary watermark image “PK”. Watermarking algorithms are usually evaluated with respect to the metrics, imperceptibility and robustness.

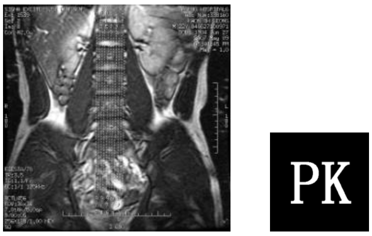
### A. Imperceptibility

The imperceptibility refers to the perceived quality of the cover image in the presence of the watermark. As a measure of the quality of a watermarked image, the peak signal to noise ratio (PSNR) is typically used. PSNR in decibels (dB) is given by,

$$PSNR \equiv 10 \times log(\frac{255^2}{MSE(W, W')}) \quad (7)$$

$$MSE(W, W') \equiv \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (W - W')^2 \quad (8)$$

where $MSE$ is the mean square error, $W$ is the original watermark sequence and $W'$ is the sequence from the extracted watermark. Fig. 4 displays the original medical image “BODY” and watermark “PK”.




(a) (b)

Fig. 4. (a) Original medical image “BODY” (512×512), (b) Original watermark “PK”.

Fig. 5 shows the watermarked medical image “BODY” and the extracted watermark.


(a) PSNR=57.33 (b) BCR=99.99 (c) The difference

Fig. 5. (a) Watermarked medical image “BODY” (512×512) with CAT Rule is 14, (b) the extracted watermark “PK”, (c) the difference between the original watermark and extracted watermark.

As shown in Fig. 5, our algorithm presents a good imperceptibility. Meanwhile, Fig. 5(c) shows the extracted watermark has nearly no difference with the original one.


(a) Rule =11 (b) Rule=12 (c) Rule=43 (d) Rule=14

Fig. 6. The extracted watermarks under different CAT rules.

The PSNR and BCR values are shown in Table I with different CAT rules.

TABLE I: THE BCR AND PSNR VALUES WITH DIFFERENT CAT RULES

| CAT rules | BCR (%) | PSNR(dB) |
|---|---|---|
| Rule=11 | 41.33 | 21.58 |
| Rule=12 | 38.29 | 19.64 |
| Rule=43 | 98.64 | 55.28 |
| Rule=14 | 99.99 | 57.33 |

## B. Robustness

The robustness refers to 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, the similarity between the original watermark and extracted watermark is measured using Bit Correct Radio (BCR), given by,

$$BCR \equiv (1 - \frac{\sum_{i=1}^{L_M} (w_i \oplus w_i')}{L_M}) \quad \times 100\% \qquad (9)$$

Here, $w_i$ is the original watermark sequence, $w_i'$ is the sequence from the extracted watermark, and $\oplus$ denotes the XOR operator.

For testing the robustness, we employed JPEG compression with quality factors, Q, of 20 and 30, Median Filter, Gaussian Noise, Sharpening and Blurring Filter to attack the watermarked image. If we can extract a watermark with higher BCR value from an attacked image, it means the robustness under the attack is ensured.

Fig. 7 displays the watermarked medical images “VESSEL” with the CAT rule 14.

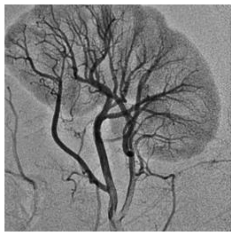
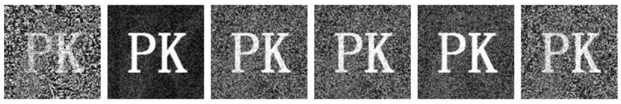


Fig. 7. (a) The Watermarked image of “VESSEL” (512x512).

Fig. 8 shows the extracted watermarks under different attacks and Table II lists the BCR values while using “VESSEL” as the test image.




(a) (b) (c) (d) (e) (f)

Fig. 8. (a) Recover watermark under JPEG compression attack, Q=20, (b) Q=30, (c) recover watermark under median filter, (d) recover watermark under Gaussian noise, (e) and (f) recover watermarks under sharpening and blurring.

TABLE II: THE BCR VALUES UNDER DIFFERENT ATTACKS.

| Attacks | BCR (%) |
|---|---|
| JPEG,Q=20 | 70.29 |
| JPEG,Q=30 | 96.54 |
| Median Filter | 78.23 |
| Gaussian Noise | 77.94 |
| Sharpening | 91.28 |
| Blurring Filter | 87.19 |

The results of the experiment under different attacks are shown in Table II. The extracted watermarks are recognizable. Our proposed method is robust to attacks, such as JPEG compression, Gaussian Noise, sharpening and blurring.

# VI. CONCLUSION

In the digital world, the security of medical images become more and more important since the communications of digital products over open network occur more and more frequently. In this work, a novel algorithm of digital watermarking based on cellular automata transform (CAT) with scrambling algorithm has been described and tested on the medical images “BODY” and “VESSEL”. Watermarking is done by embedding the level-1 CA transformed scrambling watermark into the level-2 CAT sub bands LL2, HL2, LH2 and HH2 of the medical images. The Experiment results show that watermarking by this algorithm improved the imperceptibility of the watermarked image and maintained the robustness and security to attacks. We conclude that the proposed method is expected to be useful for real-time image watermarking and transmission applications.

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