A New Colour Image Watermarking Scheme Using Cellular Automata Transform and Schur Decomposition

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Abstract: In this work a novel robust colour image watermarking scheme in Cellular Automata Transform (CAT) domain in combination with Schur decomposition is presented. Via different CA bases functions, the CAT domain provides numerous transform patterns, hence it improves the flexibility and security in data hiding. Furthermore, through Schur decomposition, highly transparency and robustness and also faster procedure in comparison with SVD-based methods is obtained. Moreover to enhance transparency and robustness, the watermark encoded by Error Correcting Code is embedded in some blocks of host image, selected by Logistic map. The experimental results confirm the efficiency of the proposed scheme.

Keywords: Image Watermarking, Cellular Automata Transform, Schur Decomposition, Logistic Map, Error Correcting Code

1. Introduction

With the rapid accessibility of the Internet as a distribution medium for multimedia data, technical solutions for protecting the intellectual property rights of digital data are perceived as a necessity [1]. Digital watermarking has been presented as a technology to guarantee copyright protection of digital multimedia content (voice, image, video, text). This is carried out by embedding an imperceptible, yet detectable signal called watermark into multimedia content, called host data [1]. The embedded signal can be used to identify the authorized user holding the copyright of digital data.

In copyright protection two main issues should be noticed: robustness and imperceptibility. Robustness indicates that embedded watermark can be extractable under most of intentional or unintentional attacks, such as cropping, filtering, additive noise and etc. Imperceptibility refers to invisibility of watermark after embedding.

Various image watermarking schemes have been presented in literatures [2-5]. According to the processing domain, in which the watermark is embedded into host image, there are two categories: spatial and transform domain. In the case of spatial domain, the watermarking is done by modifying the pixel values, while in transform domain, watermark is embedded by modifying the coefficients of transformed image. In comparison with spatial schemes, transform domain methods are more complex, but providing higher robustness and imperceptibility. Also, watermarking using the transform domain is more convenient with the human visual system [3].

Cellular Automata Transform (CAT) provides lots of planes for watermarking and this differentiates the CAT-based methods from common transform domain schemes. Schur decomposition is a matrix factorization method. Since it is an intermediate step in Singular Value Decomposition (SVD), less number of computations is required in comparison. A few watermarking methods using CAT or Schur decomposition are proposed in literatures [4,5]. Error Correcting Code (ECC) technique is one of the effective methods for improving the efficiency of any telecommunicational process. This method has been used in watermarking schemes too [3]. The colour perception depends on luminance and chrominance of the image, hence in comparison with gray image, the colour one has two advantages: more capacity and robustness [5].

It is obvious that, the higher the complexity of the watermarking scheme the more difficult will be to decode the message in illegal receiver because of the large number of the degrees of freedom of the scheme.

In this study a new image watermarking scheme for copyright protection is presented. We used colour image to attain more data hiding capacity; CAT domain to have
a secure and flexible domain; Schur decomposition to improve imperceptibility, decrease the processing time and improve the robustness; Logistic map to enhance the security and ECC to increase the efficiency of system.

In our method, the encoded watermark is embedded by modifying the Schur decomposition of CAT coefficients of host image, where just some blocks of host image, using Logistic map, are considered. The experimental results confirm the efficiency of the proposed scheme.

The rest of paper is organized as follows. The Cellular Automata Transform is described in section 2. Section 3 briefly presents the Error Correcting code. In section 4 the Schur Decomposition is given. Section 5 introduces the Logistic map. The watermarking scheme is proposed in section 6. In section 7 the experimental results are discussed and section 8 concludes the proposed method.

2. CELLULAR AUTOMATA TRANSFORM

Cellular Automata (CA) are discrete space and time dynamical systems [6]. A cellular automaton consists of uniformly arranged cells, having finite number of states which are synchronously updated according to a specified rule. Olu Lafe [6] presented Cellular Automata Transform (CAT), by using the Wolfram rule nomenclature.

A set of discrete values $\psi_i$, defined in a cellular space $i$, is expressed in the following form,

$$\psi_i = \sum_j C_j B_{ij} \quad \forall i$$  \hspace{1cm} (1)

where $B_{ij}$ are CA basis, $C_j$ are the coefficient and $j$ is a vector of natural numbers [6].

We can produce a huge set of non-orthogonal, bi-orthogonal, semi-orthogonal and orthogonal bases.

In a 2-dimensional space which consists of $N \times N$ cells, the standard orthogonal transform base, $B_{gkl}$ (i,j,k,l=0,1, … N-1), is considered as $B=B_{gkl}$. For a data sequence $\psi_i$ the direct and inverse transform can be expressed as:

$$CAT : \quad c_{kl} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \psi_i B_{gkl} / N$$ \hspace{1cm} (2)

$$ICAT : \quad \psi_i = \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} c_{kl} B_{gkl} / N$$ \hspace{1cm} (3)

Transform coefficients, $c_{kl}$, can be categorized into four categories. Those at even k and l locations express the low frequency components which are LL sub-band, and the other ones express high frequency components.

According to its inherent flexibility and complexity, CAT is an interesting research area in data hiding science. It can provide numerous transform patterns by using various CA bases functions and other specifications, and this compensates the weak point (having just one transform planes) in common transform domain schemes. In this paper we employ the CAT domain in order to achieve more secure scheme.

The CAT parameters used in this study are: Wolfram rule number is 15; N is 8; Initial configuration is 10010000; Boundary configuration is Cyclic and Basis Function is orthogonal type 8.

3. ERROR CORRECTING CODE

Error Correcting Codes (ECC) have salient refinements in watermarking methods, especially when the watermark is corrupted significantly [7]. In this study we used Reed-Solomon (RS) ECC. This code is non-binary cyclic code with m-bit sequences symbols, where m is a positive integer greater than 2. RS(n, k) can be used for any n and k, where $0 < k < n < 2m$, in which k is the number of symbols to be encoded and n is the number of encoded symbols. The resultant parities can be treated as watermark bits. Considering the size of cover and watermark image, we used RS(7,3) in this study.

4. SCHUR DECOMPOSITION

The Schur decomposition is an important tool in numerical linear algebra [8]. Schur decomposition of matrix A includes getting a unitary matrix, U, and a block upper triangular matrix, T. The direct and inverse Schur decomposition of a matrix A is given as follows:

$$Schur(A) = [U, S] \Leftrightarrow USU^T = A$$ \hspace{1cm} (4)

Schur decomposition has an interesting property of generating an invariant sub-space matrix, T, from an original complex matrix (real matrices in this paper) A.

5. LOGISTIC MAP

"The biologist Robert May emphasized that even simple nonlinear maps could have very complicated dynamics" [9]. Logistic map is a polynomial mapping, defined as

$$x_{n+1} = r x_n (1 - x_n)$$ \hspace{1cm} (5)

where $x_n$ is the state of generation x at the nth instant and $r$ is the growth rate.

Usually, $r$ is considered as $0 \leq r \leq 4$, so that $0 \leq x \leq 1$. The chaotic behaviour of the map is dependent on the parameter $r$. For $0 \leq r \leq 3$, $x_n$ has no oscillation; as $r$ grows the oscillations are born, periode-2 cycle for $r_1$ is 3, periode-4 cycle for $r_2$ is 3.449 and it continues until at $r_{\infty} \approx 3.569949$ the map becomes chaotic and the period of any $x_n$ is infinite. As we see, slight variations in the initial condition yield significant divergence in results, an inherent characteristic of chaos.

6. THE PROPOSED SCHEME

Let consider the host image (H) a 24-bit colour image with M×N size and three watermarks (W) binary images with P×Q size.
6.1 EMBEDDING PROCEDURE

The embedding procedure is organized as follows;
1) In order to increase the robustness of watermarking scheme, each watermark is firstly encoded using RS ECC.
2) The host colour image is detached into three colour channels, R, G and B component images; then the rest steps are done for each component.
3) Cellular Automata Transform is performed on host image.
4) The LL sub-band of four resultant sub-bands is selected, considering the experimental results of its robustness on common attacks, and partitioned into 4×4 non-overlapping blocks.
5) In order to improve the security and imperceptibility, some blocks using Logistic map are selected, and then Schur decomposition is implemented on each block to obtain the $U''_{ll}$ matrix.

\[
C_{ll} = U_{ll}S_{ll}U_{ll}^T \quad (6)
\]

6) $W_{ij}$, the watermark bit in position $(i,j)$, is embedded as

\[
U_{ij}' = \begin{cases} 
\text{sign}(U_{ij}) \times \text{abs}\left(\text{abs}(U_{ij}) \times T\right) & \text{if } W_{ij} = 0 \\
\text{sign}(U_{ij}) \times \text{abs}\left(\text{abs}(U_{ij}) + T\right) & \text{if } W_{ij} = 1
\end{cases} \quad (7)
\]

where $U_{ab}$ presents the element of $a^{th}$ row and $b^{th}$ column in $U$ matrix, $\text{sign}(x)$ is the sign of $x$, $\text{abs}(x)$ is the pure value of $x$ and $T$ is the embedding threshold.

7) Step 6 is repeated until all watermark bits are embedded. Then modified sub-band is obtained as

\[
C_{ll}' = U_{ll}S_{ll}U_{ll}^T \quad (8)
\]

8) The watermarked image component is attained using inverse CAT transform.

The steps 3 to 8 are done for three colour channels till three watermarks are embedded. Then, three watermarked colour components are recombined and the colour watermarked image is attained. The block diagram of embedding procedure for each colour channel is presented in Fig. 2.

6.2 EXTRACTION PROCEDURE

The extraction procedure is arranged as follows;
1) Similarly to the embedding procedure, the watermarked image is detached into three $R, G$ and $B$ colour channels, and then the rest steps are done for each colour component.
2) Cellular Automata Transform is performed on image, and four frequency sub-bands are attained.
3) The LL sub-band of resultant sub-bands is partitioned into 4×4 non-overlapping blocks and the same blocks which were used in embedding procedure are selected using Logistic map.
4) Schur decomposition is implemented on each block to obtain the $U'$ matrix.
5) The watermark image is extracted as follows;

\[
W_{ij}' = \begin{cases} 
0 & \text{if } \text{abs}(U_{ij}''_{11}) < \text{abs}(U_{ij}''_{21}) \\
1 & \text{if } \text{abs}(U_{ij}''_{11}) \geq \text{abs}(U_{ij}''_{21})
\end{cases} \quad (9)
\]

where $\text{abs}(x)$ presents pure value of $x$ and $U''_{ab}$ is the element of $a^{th}$ row and $b^{th}$ column in $U''$ matrix.

6) Step 5 is repeated until all embedded information is extracted. Then the RS decoding is implemented on extracted data and then watermark is obtained.

The steps 2 to 6 are done for each colour channel till three watermarks are extracted. The block diagram of extraction procedure for each component is presented in Fig. 3.

It should be noted that CAT’s parameters, Logistic map’s keys and $m, k$ and $n$ as parameters of ECC technique are secret keys and ensure the authorized access to the watermark.

7. EXPERIMENTAL RESULTS

In order to test the actual performance of the proposed method, we examined the method with different well-known 24 bit colour images with 1024 × 1024 size, using three binary images with 63×63 size, as are shown in Fig.1.

The performance of any robust watermarking scheme is examined by measuring the imperceptibility and robustness. For the imperceptibility parameter, the Peak Signal-to-Noise Ratio (PSNR) is used to give the difference between the original host and watermarked image. For the robustness parameter, the Normalized Correlation (NC) measure is used, which gives the similarity between the original and extracted watermark. PSNR and NC are defined as fallows.

PSNR is the mean of PSNR$_i$, where PSNR$_i$ $(i=1,2,3)$ indicates the PSNR of colour channel $i$ and is defined as

\[
PSNR_i = 10\log_{10} \frac{M \times N}{\min\{H(x,y,i) - H'(x,y,i)\}^2} \quad (10)
\]

![Fig. 1. Test images, host images: (a) Mashhad, (b) Peppers, (c) Baboon and (d) F16; Watermark images: (e) Muhammad, (f) Ali and (g) Fatima](image-url)
where \(H(x,y,i)\) and \(H'(x,y,i)\) present the value of pixel at position \((x,y)\) in \(i\) colour component of the host image, \(H\), and watermarked image, \(H'\), with the size \(M \times N\).

The NC factor for the original watermark image, \(W\), and the extracted one, \(W'\), with the size \(P \times Q\), is defined as:

\[
NC = \frac{\sum_{x=1}^{P} \sum_{y=1}^{Q} (W(x,y) - W'(x,y))^2}{\sqrt{\left(\sum_{x=1}^{P} \sum_{y=1}^{Q} W(x,y)^2\right) \left(\sum_{x=1}^{P} \sum_{y=1}^{Q} W'(x,y)^2\right)}}
\]

(11)

It is clear that the higher PSNR confirms the more similarity of the watermarked and original image, implying the imperceptibility of the scheme. Also the higher the NC results, the more similar the original and extracted watermarks would be, declaring the robustness of the scheme.

As mentioned before, \(T\) is a threshold in embedding procedure and should be set in a way that ensures the robustness and transparency of method. In this study we set \(T=0.005\) to obtain the PSNR for watermarked images around 45dB, to ensure the imperceptibility of watermarking.

The robustness of proposed scheme is examined under different attacks including Gaussian noise, JPEG compression, low-pass filtering, image rotation, image cropping, salt and pepper noise, histogram equalization, median filtering, gamma correction, image blurring and image sharpening. A detailed simulation result for all test images is presented in Table I. From Table I we can see that the NC parameter for all test images is near to 1; this confirms the robustness of proposed scheme to common image processing attacks. Also a comparison of the performance of proposed method with recently presented methods is presented in Table II, where confirms the efficiency of proposed system.

8. CONCLUSION

In this study a new colour image watermarking scheme for copyright protection is presented. Using the CAT domain we gain numerous transform patterns, hence flexibility and security improves, compensating the week point having just one transform plan of common transform domain schemes. Furthermore, by using Schur decomposition we improved the robustness and imperceptibility of method, also the procedure became faster in comparison with SVD-based methods. In order to attain more security and transparency, we did embedding on some blocks of image, selected by Logistic map, and in order to improve the robustness, watermark is encoded using Reed-Solomon ECC technique before embedding. On the other hand, using the colour host image improves the capacity of watermarking system. The experimental results confirm the transparency and
robustness of proposed scheme against most of common attacks.

REFERENCES


$$\text{TABLE I}
\begin{array}{|c|c|c|c|}
\hline
\text{Attacks} & \text{Mashhad} & \text{Peppers} & \text{F16} \\
\hline
\text{No Attack} & 45.24 & 46.35 & 46.27 \\
\text{PSNR} & 44.03 & 45.09 & 43.76 \\
\text{NC} & 1.0000 & 1.0000 & 1.0000 \\
\hline
\text{JPEG (35\%)} & 0.8817 & 0.8776 & 0.9046 \\
\text{PSNR} & 45.91 & 47.38 & 45.85 \\
\text{NC} & 0.9404 & 0.9211 & 0.9874 \\
\hline
\text{Median Filter (3*3)} & 0.9989 & 1.0000 & 1.0000 \\
\text{PSNR} & 46.05 & 47.09 & 45.44 \\
\text{NC} & 0.9989 & 1.0000 & 1.0000 \\
\hline
\text{S & P Noise (0.05)} & 39.01 & 39.36 & 38.82 \\
\text{PSNR} & 31.47 & 31.66 & 31.41 \\
\text{NC} & 0.8909 & 0.8855 & 0.9086 \\
\hline
\text{Gaussian Noise (0.05)} & 27.70 & 43.96 & 25.14 \\
\text{PSNR} & 0.8006 & 0.7962 & 0.8415 \\
\text{NC} & 1.0000 & 1.0000 & 1.0000 \\
\hline
\text{Histogram Equalization} & 28.06 & 27.53 & 33.78 \\
\text{PSNR} & 0.9431 & 0.8101 & 0.7088 \\
\text{NC} & 0.9664 & 0.9642 & 0.9977 \\
\hline
\text{Gamma Correction} & 36.18 & 37.78 & 36.60 \\
\text{PSNR} & 32.29 & 32.96 & 32.83 \\
\text{NC} & 0.9664 & 0.9642 & 0.9977 \\
\hline
\text{Image Blurring} & 27.62 & 27.89 & 27.59 \\
\text{PSNR} & 0.7581 & 0.7683 & 0.6894 \\
\text{NC} & 0.8770 & 0.8705 & 0.8952 \\
\hline
\text{Image Sharpening} & 38.02 & 39.86 & 38.09 \\
\text{PSNR} & 0.9846 & 0.9793 & 1.0000 \\
\text{NC} & 0.9664 & 0.9642 & 0.9977 \\
\hline
\end{array}
$$

$PSNR$ and $NC$ refers to the average $PSNR$ and $NC$ of three colour channels and three extracted watermark images respectively.

$\text{TABLE II}
\begin{array}{|c|c|c|c|}
\hline
\text{Attack} & \text{[10]} & \text{[8]} & \text{Proposed Scheme} \\
\hline
\text{Salt and Pepper noise} & 0.01 & 0.2344 & 0.8017 & 0.8023 \\
\text{Median Filtering} & 1.0023 & 0.6715 & 0.9102 & 0.9560 \\
\text{Image Sharpning} & 0.2 & 0.5502 & 0.9889 & 0.9877 \\
\text{Image Blurring} & 1.0 & 0.6258 & 0.9821 & 0.9800 \\
\text{Histogram Equalization} & 0.2 & 0.5718 & 0.9889 & 0.9897 \\
\text{Gamma Correction} & 1.0 & 0.1785 & 0.8010 & 0.8711 \\
\hline
\end{array}$
