A Novel Gray Image Watermarking Scheme

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***Abstract*—An effective and integrated image watermarking scheme mainly includes watermark generation, watermark embedding, watermark identification, and watermark attack. In this paper, a novel discrete wavelet transform domain image watermark scheme is proposed to meet the watermarking properties: security, imperceptibility and robustness. Here watermark comes from a meaningful binary image encrypted by two-dimensional chaotic stream encryption, which has more security. In the procedure of watermark embedding, the watermark is embedded into host image through selecting and modifying the wavelet coefficients using genetic algorithms with a simple fitness function to improve the imperceptibility of watermarked image. In order to identify the owner of extracted watermark, synergetic neural networks are used in the watermarking identification to overcome the limitation of correlation analysis or the human sense organ after some attacks. The results of our scheme realization and robust experiments show that this scheme has preferable performance.**

***Index Terms*—image watermark, genetic algorithm, synergetic neural networks, discrete wavelet transform**

I. INTRODUCTION

Digital watermark is a kind of technology that embeds copyright information into multimedia data[1]. Unlike encryption, which is useful for transmission but does not provide a way to examine the original data in its protected form, the watermark remains in the content in its original form and does not prevent a user from listening to, viewing, examining, or manipulating the content. Digital watermarking technology opens a new door to authors, producers, publishers, and service providers for protecting their rights and interests in multimedia documents.

An effective image watermarking scheme mainly includes watermark generation, watermark embedding, watermark identification, and watermark attack. Watermark generation refers to what content and form of data a watermarking scheme adopts as watermark. The data may be original or encrypted from copyright information of number, letter, image, and so on. Some of copyright information is meaningful or meaningless. Meaningful information could be easily authenticated and usually needs to be encrypted in practice to strengthen watermarking security [2].

Watermark embedding is the most important part in a watermarking scheme and must meet the two most fundamental requirements under the condition of fixed watermark size, imperceptibility and robustness. The two requirements are in conflict with each other and need to reach a trade-off. Watermark embedding can be done in either spatial domain or frequency domain. The spatial domain watermark embedding manipulates host image pixels, especially on least significant bits that have less perceptual effect on the image[3]. Although the spatial domain watermark embedding is simple and easy to implement, it is less robust than frequency domain watermark embedding to various attacks and noise, which is made on the frequency coefficients of the host image. The existing frequency transformation methods for watermark embedding include discrete Fourier transform (DFT) [4], discrete cosine transform (DCT)[5], and discrete wavelet transform (DWT)[6]. Considering watermarking imperceptibility, we need to select an

Manuscript received November 15, 2010; revised January 21, 2011; accepted January 1, 2011.
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Project number: National 863 Hi-Tech Grant 2009AA01Z411

doi:10.4304/jsw.6.5.849-856

appropriate embedding algorithm to embed the watermarking bits into certain frequency coefficients so that the quality of watermarked image does not obviously decline compared by original host image. But many traditional embedding algorithms in the literature can not optimize the embedding process by experiential method. In recent years, watermarking techniques have been improved using optimization algorithms such as genetic algorithm (GA) which is a popular evolutionary optimization technique invented by Holland [7]. In the field of watermarking, GA is mainly used in the embedding procedure to search for locations to embed the watermark [8-11].

The act of watermark detection can be named as watermark verification that a watermarking receiver must do a yes or no judgment whether a watermark does exist in the received image. In general, the normalized cross-correlation (NC) value between the original and extracted watermark is used in watermark detection [11]. Defined a threshold *T*, a yes judgment can be given if NC $\geqslant T$, or a contrary result will be gotten. After getting a yes judgment in watermark detection, especially to the meaningful watermark, people may do more things to judge the owner of extracted watermark because of possibility of spurious watermark. Based on the watermark detection, watermark identification is to farther judge what degree extracted watermark is similar to original watermark and whose extracted watermark belongs to. Although bit correct rate (BCR), NC and human eyes can be used in watermark identification, they all depend upon experimental results and human experiences. For distinguishing extracted watermark more clearly, meaningful watermark may be recovered partly or entirely from watermarked image by neural networks [12-14]. The introduction of neural networks helps to pave the way for the further development of watermark identification techniques.

The goal of watermark attack is to test the robustness of a watermarking system. To simulate the communication conditions and deliberate or unintentional processing, some attacks, including adding noise, filtering, compression and geometrical distortion, need to be used in the watermarked image. For copyright protection, we use robust watermark in the condition that the watermark can partially be recognized and the copyright can be preserved after attacked by some means. But based on the applied purpose of robust watermark, a watermarking scheme need not withstand all kinds of attack.

This paper presents a novel DWT domain gray image watermarking scheme. The watermarking data comes from a meaningful binary image encrypted by two-dimensional chaotic stream encryption. In the procedure of watermark embedding, GA is used to select the most fit wavelet coefficients to embed watermarking bits into the host gray image. After some kinds of attack, the extracted watermark can be identified expediently through the synergetic neural networks(SNN). The experimental results have shown that this scheme has preferable performance of security, imperceptibility and robustness.

II. WATERMARK GENERATION

The paper [2] employed the two-dimensional chaotic Logistic map to encrypt the meaningful gray image and gave the digital image stream encryption algorithm in detail. Here, we simplify the algorithm to encrypt a binary image.

The two-dimensional Logistic map system with simple coupled term is defined in (1).

$$\begin{cases} x_{n+1} = 4\mu_1 x_n (1 - x_n) + \gamma y_n \\ y_{n+1} = 4\mu_2 y_n (1 - y_n) + \gamma x_n \end{cases} \tag{1}$$

The dynamical behavior of this map system is controlled by control parameters of μ_1, μ_2 and γ. When $\mu_1 = \mu_2 = \mu \geq 0.89$ and $\gamma = 0.1$, the system is chaotic and can be used in digital image encryption.

Let $\mathbf{B} = [b_{s,t}]_{M\times M}$ represent a meaningful binary image with size $M \times M$, $0 \leq s \leq M-1$, $0 \leq t \leq M-1$, $b_{s,t} \in \{0,1\}$. x_P and y_P are values obtained after the map system is iterated P times. Using iterative values x_i and y_i, encryption algorithm is described as follows.

1)Transform the decimal fraction of x_i into binary sequence and choose the first M bits to be represented as $x_{i,0}x_{i,1}\cdots x_{i,M-1}$. Like x_i, the decimal fraction of y_i is represented as $y_{i,0}y_{i,1}\cdots y_{i,M-1}$.

2)According to the row order $s = 0,1,2,\cdots,M-1$ and $i = P+s$, do the XOR operation $c_{s,t} = b_{s,t} \oplus x_{i,j}$, $j = t$.

3)According to the column order $t = 0,1,2,\cdots,M-1$ and $j = t$, do the XOR operation $w_{s,t} = c_{s,t} \oplus y_{i,j}$, $i = P+s$.

The watermark $\mathbf{W} = [w_{s,t}]_{M\times M}$ can be gotten by completing above three steps.

Let $\widehat{\mathbf{W}} = [\widehat{w}_{s,t}]_{M\times M}$ represent the extracted watermark from watermarked image, the decryption procedure is described as follows.

1)The decimal fraction of x_i and y_i are denoted by $x_{i,0}x_{i,1}\cdots x_{i,M-1}$ and $y_{i,0}y_{i,1}\cdots y_{i,M-1}$ respectively.

2)According to the column order, do XOR operation $\hat{c}_{s,t} = \widehat{w}_{s,t} \oplus y_{i,j}$.

3)According to the row order, do XOR operation $\hat{b}_{s,t} = \hat{c}_{s,t} \oplus x_{i,j}$ and get decrypted image $\widehat{\mathbf{B}} = [\hat{b}_{s,t}]_{M\times M}$.

From the above encryption and decryption algorithms, it can be concluded that if the received image has not been processed, the equations $\widehat{\mathbf{W}} = \mathbf{W}$ and $\widehat{\mathbf{B}} = \mathbf{B}$ are satisfied after the decryption.

III. WATERMARK EMBEDDING

Wavelet transform is a time-frequency analyzing method to localize spacial and frequency domain. Using wavelet transform to code and compress image can acquire good effect having high compress ratio and no avail of block and midge noise. In our scheme, the encrypted watermark is embedded into host image through selecting and modifying the wavelet coefficients using GA.

A. Genetic Algorithm

GA is a kind of best searching algorithm that simulates biological evolution to produce a similar optimal solution and widely used in various fields such as pattern recognition, decision support and the nearest optimization problem. In organism evolution, organisms with defective genes are weeded out so that a species of organisms preserves its beneficial genes for its descendants. Generally, better chromosomes will be produced for propagation after crossover or mutation.

The GA can be briefly depicted as follows.

1) Code. In GA-based optimization, any possible solution in problem field is represented as an individual in colony and encoded by a finite-length binary string, called the chromosome. The elements in the binary string, or the genes, are adjusted to minimize or maximize the fitness value.

2) Original colony. Some individuals or chromosomes are selected in random to form original colony as the first generation that can reproduce new generation.

3) Fitness evaluation. The fitness function is defined by algorithm designers, with the goal of optimizing the outcome for the specific application. For every generation, a pre-determined number of chromosomes will correspondingly produce fitness values. The fitness values decide the probability of the chromosomes' survival or removal during the competition. Chromosomes with higher fitness values have higher probability to contribute more offspring in the next generation.

4) Genetic operation. Three GA operators, selection, crossover and mutation, the core components for GA, are applied to the chromosomes repeatedly.

Selection: A large portion of the chromosomes with low fitness values is discarded through this natural selection step. The selection rate P_s defines the portion of chromosomes with high fitness values that can be survived into the next generation.

Crossover: Pairs of chromosomes among the survived chromosomes are chosen from the current generation to produce two new off-springs. A crossover point is selected, and the fractions of each chromosome after the crossover point are exchanged, and two new chromosomes are produced.

Mutation: Mutation is the occasional random alternation of the value in some positions of chromosomes. It introduces traits not in the original individuals and keeps GA from converging too fast. Most mutations deteriorate the individual fitness values. However, the occasional improvement of the fitness adds diversity and strengthens the individual. Generally speaking, the probability P_m for mutation is supposed to be low.

These operators are used repeatedly to obtain successive generations of chromosomes. Within a generation, only the chromosomes with the higher fitness values can survive. They will be passed as parent chromosomes to the next generation.

5) Terminating rule. The terminating rule can be selected as one of conditions that the generation number is more than a defined terminating number or the fitness values of chromosomes is unchanged after some generations.

After a number of generations, the chromosomes are optimized. We can obtain the near-optimal solution of the modeled problem.

B. Embedding algorithm using GA

Embedding algorithms using GA in DWT domain image watermark have been researched in some papers. GA is applied to improve the quality of the watermarked image and the robustness of the watermark. But, the main drawback in these algorithms lies in the fitness function which is developed based on the combination of imperceptibility and robustness. The objective functions used to measure these properties vary significantly by numerical values. The varieties of attacks make difficult for equal contribution of imperceptibility and robustness in fitness function even if robustness measure is scaled by a factor. In our embedding algorithm based on GA, a simple fitness function may be developed only considering imperceptibility rather than robustness dealt with in the procedure of watermark identification.

Let $\mathbf{I}=[I(i,j)]$ ($1\le i,j\le N$) represent the host gray image with size $N\times N$ and $\hat{\mathbf{I}}$ be the optimal watermarked image. The embedding algorithm is outlined below in detail.

1) Divide the host image into ordinal un-overlapped $2M\times 2M$ sub-images. There are $\frac{N}{2M}\times\frac{N}{2M}$ sub-images represented by $I_{i,j}$ ($1\le i,j\le \frac{N}{2M}$).

2) Perform discrete wavelet transform independently to every sub-image $I_{i,j}$ and get the sub-image low subband $\mathbf{LL}_{i,j}=[LL_{i,j,s,t}]$, high subband $\mathbf{HH}_{i,j}$, two middle subbands $\mathbf{HL}_{i,j}=[HL_{i,j,s,t}]$ and $\mathbf{LH}_{i,j}=[LH_{i,j,s,t}]$. Because the texture and edge information are mainly represented in the biggish wavelet coefficients of HH, HL and LH subbands, the watermark will be embedded into the low or middle subband.

3) There are $\frac{N}{2M}\times\frac{N}{2M}\times 3$ subband positions in the host image so the chromosome is encoded to $\log_2(\frac{N}{2M}\times\frac{N}{2M}\times 3)$ bits . Each chromosome represents a position to embed the watermark.

4) For one chromosome, modify the corresponding coefficients as (2) and (3).

$$LL'_{i,j,s,t}=\begin{cases} LL_{i,j,s,t}+\dfrac{\alpha_1}{M^2}\left|\sum_{s=1}^{M}\sum_{t=1}^{M}LL_{i,j,s,t}\right| & if\ w_{s,t}=1 \\ LL_{i,j,s,t}-\dfrac{\alpha_1}{M^2}\left|\sum_{s=1}^{M}\sum_{t=1}^{M}LL_{i,j,s,t}\right| & if\ w_{s,t}=0 \end{cases} \quad (2)$$

$$CF'_{i,j,s,t}=\begin{cases} CF_{i,j,s,t}+\dfrac{\alpha_2}{M^2}\sum_{s=1}^{M}\sum_{t=1}^{M}\left|CF_{i,j,s,t}\right| & if\ w_{s,t}=1 \\ CF_{i,j,s,t}-\dfrac{\alpha_2}{M^2}\sum_{s=1}^{M}\sum_{t=1}^{M}\left|CF_{i,j,s,t}\right| & if\ w_{s,t}=0 \end{cases} \quad (3)$$

The parameter α_1 and α_2 are the embedding intensities and CF maybe one of HL and LH. Do inverse discrete wavelet transform after modifying the wavelet coefficients and get $I'_{i,j}$. All of $I'_{i,j}$ are united to a watermarked image $\mathbf{I}'=[I'(i,j)]$ $(1\le i,j\le N)$.

5) Define the fitness function using peak signal-to-noise ratio (PSNR) between $\mathbf{I}=[I(i,j)]$ and $\mathbf{I}'=[I'(i,j)]$.

$$PSNR=10\times\log_{10}\left(\frac{N^2\times\max(I^2(i,j))}{\sum_{i=1}^{N}\sum_{j=1}^{N}(I(i,j)-I'(i,j))^2}\right) \quad (4)$$

6) Create some random chromosomes into an original colony and give the values of P_s and P_m. Evaluate the fitness values of chromosomes and do the genetic operation until the process of GA stops and the optimal watermarked image $\hat{\mathbf{I}}$ is gotten.

The final chromosome of GA and parameters $(\mu_1,\mu_2,\gamma,x_0,y_0,P)$ of the two-dimensional chaotic Logistic map system can be looked upon the key of this watermarking scheme used in watermark extraction.

IV. Watermark Identification

To an encrypted meaningful watermark extracted from watermarked image, people maybe not distinguish its decrypted form through technical indexes, such as BCR, NC, and eyes, because of some interferential causations to watermarked image in the communication and usage. The SNN can effectively identify the extracted watermark in our former research[15] so that it is used in this scheme too.

A. Synergetic Neural Networks

The SNN model is a top-down network constructed by synergetic different from traditional network constructed by the method researched in single neuron's characteristic, configuration and connection[16].

Dynamical system can be described by state vector in Synergetic. Let a state vector be $q=(q_1,q_2,\cdots,q_{M'})$. A synergetic associative pattern recognition system can be described by dynamical evolutionary process, in which the system evolves by neural network learning to fill incomplete data set and form pattern. Furthermore, let prototype pattern number be M' and prototype pattern vector's dimension be N', where satisfies $M'\le N'$. A dynamical equation can be described by (5).

$$\dot{q}=\sum_k\lambda_k v_k(v_k^+q)-B\sum_{k\neq k'}(v_{k'}^+q)^2(v_k^+q)v_k-C(q^+q)q \quad (5)$$

where q as recognizable pattern vector with original input value $q_0=q(0)$ can be decomposed into prototype v_k and remnant vector w, having $q=\sum_{k=1}^{M'}\xi_k v_k+w$ and $v_k^+w=0$. Attention parameter λ_k is positive. B and C are appointed coefficients and must be more than zero. Prototype pattern vector v_k is expressed as $v_k=(v_{k1},v_{k2},\cdots v_{kN'})'$ and v_k^+ is an adjoint vector of v_k, which satisfies an orthogonal condition $v_k^+v_k=\delta_{kk'}=\begin{cases}1,k=k'\\0,k\neq k'\end{cases}$. All v_k will be normalized as $\sum_{l=1}^{N'}v_{kl}=0$ and centered as $\|v_k\|_2=(\sum_{l=1}^{N'}v_{kl}^2)^{1/2}=1$.

Order parameter ξ_k is defined as $\xi_k=v_k^+q$. The dynamical equation can be rewritten by order parameter.

$$\dot{\xi}_k=\lambda_k\xi_k-B\sum_{k'\neq k}\xi_{k'}^2\xi_k-C(\sum_{k'=1}^{M'}\xi_{k'}^2)\xi_k \quad (6)$$

Used $D=(B+C)\sum_{k'}\xi_{k'}^2$, (6) is simplified to (7).

$$\dot{\xi}_k=\xi_k(\lambda-D+B\xi_k^2) \quad (7)$$

So the SNN model is constructed with three layers. The top layer is the input layer. All order parameter neurons form the middle layer. The down layer is the output layer.

B. Watermark Extracting

The watermark extracting is the contrary producer of watermark embedding. The DWT transforms of the received watermarked image $\hat{\mathbf{I}}$ and host image $\mathbf{I}$ could be done according to the rule of watermark embedding and the final chromosome of GA need be gotten from the key. The extracted encrypted watermark $\widehat{\mathbf{W}}$ can be extracted by (8).

$$\begin{cases} CF'_{i,j,u,v} - CF_{i,j,u,v} > 0 \quad \Rightarrow \quad w_{s,t} = 1 \\ CF'_{i,j,u,v} - CF_{i,j,u,v} < 0 \quad \Rightarrow \quad w_{s,t} = 0 \end{cases} \tag{8}$$

The CF presents one of LL, HL and LH.

Then using the parameters $(\mu_1, \mu_2, \gamma, x_0, y_0, P)$ of the two-dimensional chaotic Logistic map system from the key and decryption algorithm, we can decrypt the extracted encrypted watermark $\widehat{\mathbf{W}}$ and get the decrypted watermark $\widehat{\mathbf{B}}$.

C. Decrypted Watermark Identification using SNN

The decrypted watermark identification may be taken for the process that a special existing watermark is formed and recognized in a mass of watermark patterns so that the pattern recognition method may be used in the watermark algorithm.

The original meaningful watermark image and some binary images having the same size and similar content as the watermark image are select to makeup a prototype pattern set including M' components. All of two-dimensional binary images are transferred to one-dimensional sequences and the vectors $v_k = [v_{k1}, v_{k2}, \cdots, v_{kN'}]^T$ ($k = 1, 2, \cdots, M'$, $N' = M^2$) can be gotten. A prototype pattern set may be composed of these M' pattern vectors only if $M' \le N'$.

According to the SNN model, the learning algorithm of networks is the training process that adjoins vectors are calculated through prototype pattern vector.

1) Compute prototype pattern vector v_k satisfying normal and center condition.

2) Compute the according adjoint vector v_k^+ of prototype pattern vector v_k.

Used the SNN method, the watermark detection and identification may be accomplished at one time through recognized pattern. Now the constants of synergetic dynamic equation are given to $B = C = 1$ and $\lambda_k = 1$. Thus the recognition process of SNN is showed as following.

1) Compute the test pattern vector $q(0) = \{q_i\}$, $i = 1, 2, \cdots, N'$, which satisfying normal and center condition, too.

2) Achieve the according order parameter $\xi_k(0)$ of prototype patterns. According to synergetic slaving principle, the pattern having the most value of order parameters will prevail in the synergetic evolution, and thus the watermark embedded in the host image carrier may be detected firstly.

3) Evolve by (7) until the neural networks becomes stabilized to specific prototype pattern.

The decrypted watermark sequence represented by the special prototype pattern can revert to the original meaningful watermark so that the decrypted watermark is identified.

V. Scheme Realization and Robust Experiments

In order to test the validity of the proposed scheme, we select Peppers image as host gray image with size $N = 512$ and a binary face image as original meaningful image with size $M = 64$ treated from The Database of Faces [17]. In the mean time, other four binary face images are selected to compose a prototype pattern vector set including five one-dimensional vector components with the original watermark. Therefore there are $M' = 5$ components in the prototype pattern set. The images used in our scheme are all listed in Fig.1.

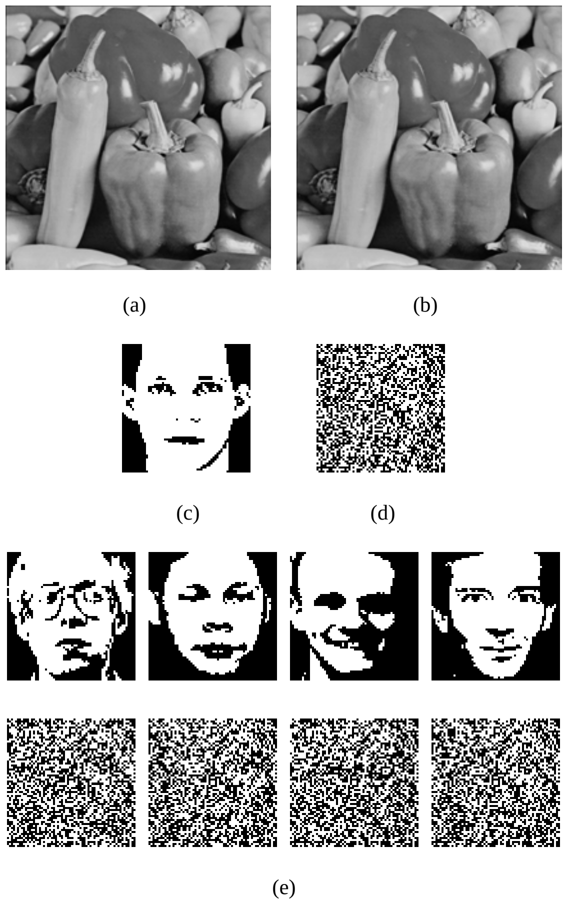


Figure 1. Images in the scheme

After selected control parameters $\mu_1 = \mu_2 = \mu = 0.9$, $\gamma = 0.1$ and initial values $x_0 = 0.1$, $y_0 = 0.11$, $P = 500$, the binary face image is encrypted to watermark used the encryption algorithm. The face image and watermark are showed in Fig.1(b) and Fig.1(d) respectively.

The embedding intensities $\alpha_1 = 0.02$ and $\alpha_2 = 1.5$ are set firstly. Used GADS Toolbox in the Matlab7.0, the watermark is embedded into the peppers image. The host Peppers image and watermarked Peppers image are showed in Fig.1(a) and Fig.1(c). In the GA, the best position $\mathbf{LL}_{2,1}$ and the most value of PSNR 53.1417 are gotten through about 15 generations.

To image watermark, the possible attacks in the usage are adding noise, range change, linear filter, and lossy compression, which used to review the image watermark's robustness. In the Matlab7.0 software environment, we accomplished attack experiments to the watermarked Peppers image: adding gaussian noise with zero mean and 0.0005 variance, adding salt-pepper noise which zero mean and 0.0005 variance, strengthening contrast from [0.1 0.9] to [0 1], weakening contrast from [0 1] to [0.1 0.9], doing 3×3 median filter and wiener filter, and JPEG compression with quality 50%. After these attacks, the extracted watermark can be identified rightly by SNN in the 20-50 steps of evolution and some robust experimental results are showed in Figs. 2-8. In these figures, (a) are extracted watermarks, (b) are encrypted images of extracted watermarks, and (c) are evolution lines of SNN.

(a) (b) (c)

Figure 2. Evolution of robust experiments for Gaussian noise

(a) (b) (c)

Figure 3. Evolution of robust experiments for salt-pepper noise

(a) (b) (c)

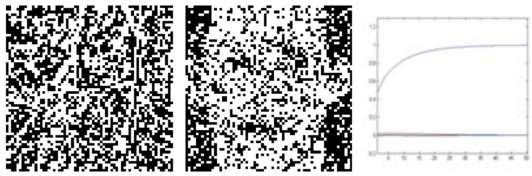
Figure 4. Evolution of robust experiments for strengthen

(a) (b) (c)

Figure 5. Evolution of robust experiments for weaken

(a) (b) (c)

Figure 6. Evolution of robust experiments for median filter



(a) (b) (c)

Figure 7. Evolution of robust experiments for wiener filter

(a) (b) (c)

Figure 8. Evolution of robust experiments for JPEG compression

From the Figs. 2-8, we can see that some extracted watermarks in Fig.3, Fig.5 and Fig.8 can be directly identified by our eyes or correlation analysis, but others in Fig.2, Fig.4 and Fig.6 can't be. Used the SNN, the SNN evolution results of watermarks tends to 1 and the watermarks embedded in the host image could be easily identified.

VI. CONCLUSION

An effective digital watermark scheme must meet three main properties: security, imperceptibility and robustness. In our scheme the two-dimensional chaotic stream encryption is used to encrypt a meaningful image to generate a watermark. The watermark encrypted from a meaningful image can not be fabricated so that there is very strong watermarking security. GA is adopted to find the best position to embed watermark to wavelet coefficients of host image in order to guarantee the quality of watermarked image. This kind of evolutionary optimization technique can improve watermarking imperceptibility and robustness. In the procedure of watermarking identification, SNN has the ability to recognize the original watermark quickly and accurately after attacks.

In our scheme realization and robust experiments, the results prove the feasibility and validity of our proposed scheme. But in the watermarking embedding, one of the limitations is that the embedding intensity is given by experience in this scheme. In the next step, we will use GA to find the best value of embedding intensity to improve embedding performance. It is better that GA could be used to select the embedding position and intensity synchronously.

ACKNOWLEDGMENT

This work was supported in part by grants from the National 863 Hi-Tech Grant 2009AA01Z411 and the 2008 importance project of Wuhan Textile University.

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