Color Image Hiding Using Neural Networks with Grey Relation Based on Interpolative Vector Quantization

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Abstract

In this paper, a novel color image hiding technique using spread grey-based competitive Hopfield neural network (SGHNN) and Hadamard Transform (HT) digital watermarking is proposed. The goal is to offer secure communications in the internet through compress the original color image and embedded into another disguise color image. Our method includes a spread-unsupervised competitive Hopfield neural network with grey relational analysis for color image compression based on interpolative vector quantization (IVQ). Then we embedded color IVQ indices and sorted codebooks of original color image information into a disguise color image by HT-based watermarking so that design a security color image hiding is feasible.

Keywords: interpolative vector quantization, grey theory, neural networks, and Hadamard transform.

1. Introduction

Color images are widely used in our daily lives. The major issue of compression and security for color image has seen an explosive growth in computers, networks, communications and multimedia applications.

A cryptosystem is a useful tool for information security [1]. However, most traditional cryptosystems were only designed to protect text data. They are not suitable to encrypt image directly. Recently there have been several cryptosystems proposed for gray image security [2-5]. In this paper, we focus on the subject of joint color image compression and color image watermarking to protect color image information for secure communications in the internet.

In our presented color image hiding approach, we employ a disguise color image to camouflage our original color image to be an embedded color image. The embedded color image is one that can be made public. In addition, for the purpose of reducing massive hiding color image information, the interpolative color Vector Quantization (VQ) is adopted.

Neural networks with competitive learning have been demonstrated by the authors capable of performing vector quatization [6-8]. In this paper, we presented a Spread Grey-based competitive Hopfield Neural Network (SGHNN) for color image compression based on Interpolative VQ (IVQ).

Furthermore, based on the presented scheme, we developed digital watermarking software to hid color image information. The original color image is first compressed by the SGHNN based on interpolative VQ into the color IVQ indices and sorted codebooks which is then embedded into the Hadamard transform domain of the original color image.

2. Background

2.1 Competitive Hopfield Neural Network

For n training vectors and c classes, the discrete Hopfield neural network with competitive learning (called CHNN) [9-10] consists of $n \times c$ neurons, which can be conceived as a two-dimensional array. Each vector is iteratively trained to update the weight of the neurons by using the nearest neighbor rule. In a 2-D Hopfield neural network, let $V_{y,j}$ be the output state of the $(y,j)th$ neuron and $\mathbf{W}_{x,i;y,j}$ represents the interconnected weight between neuron (x,i) and neuron (y,j). A neuron (x,i) in the network receives weighted inputs $\mathbf{W}_{x,i;y,j}$ from each neuron (y,j) and a bias $\mathbf{I}_{x,i}$ from outside. The total input to neuron (x,i) is computed as

$$Net_{x,i} = \sum_{y=1}^{n}\sum_{j=1}^{c} \mathrm{W}_{x,i;y,j} V_{y,j} + \mathrm{I}_{x,i} \qquad (1)$$

and the Lyapunov energy function of the two-dimensional Hopfield neural network is given by [10]

$$E = -\frac{1}{2}\sum_{x=1}^{n}\sum_{y=1}^{n}\sum_{i=1}^{c}\sum_{j=1}^{c} V_{x,i}\mathbf{W}_{x,i;y,j}V_{y,j} - \sum_{x=1}^{n}\sum_{i=1}^{c}\mathbf{I}_{x,i}V_{x,i} \qquad (2)$$

The network reaches a stable state when the Lyapunov energy function is minimal.

2.2 Digital Watermarking

Digital watermarking is a technique to embed a secret data in a digital image or video sequence that allows ownership to be identified. The earlier watermarking techniques were spatial domain [11-12]. Spatial domain method analyzes the original data in spatial domain and manipulates Least Significant Bit (LSB) to embed watermark data.

Most of current transform domain watermarking techniques use Discrete Cosine Transform (DCT) [13-15], Discrete Fourier Transform (DFT) [16] and Discrete Wavelet Transform (DWT) [17-18]. Frequency domain method converts the original data and watermark data into frequency domain and then manipulates the coefficients to embed watermark data into the original multimedia data.

3. Color Image Hiding

In this paper, the proposed scheme is a combination between color image compression based on interpolative VQ and digital watermarking techniques. The goal of color image compression based on interpolative VQ is to reduce massive hiding data in the digital representation of a color image. In order to achieve high compression ratio with less distortion, we presented a spread grey-based competitive Hopfield neural network for color image compression scheme.

Consider an original color image that we want to offer secure communications in the internet by our proposed scheme. We must first choose another disguise color image to camouflage it. Since our scheme is based on interpolative VQ, two data items need to be hided. One is the sorted codebook. The other is a set of indices on the sorted codebook. The relative illustrations are described as follows.

3.1 Color Image Compression Using SGHNN Based on VQ

Suppose an image is divided into n blocks (vectors of pixels) and each block occupies $\ell \times \ell$ pixels. A vector quantizer is a technique that maps the Euclidean $\ell \times \ell$ -dimensional space $\mathbf{R}^{\ell\times\ell}$ into a set $\{\boldsymbol{\omega}_j, j = 1,2,...,c\}$ of points in $\mathbf{R}^{\ell\times\ell}$, called a codebook. It looks for a codebook such that each training vector is approximated as close as possible by one of the code vectors in the codebook. A codebook is optimal if the average distortion is at the minimum value. The average distortion $E[d(\mathbf{x}_y, \boldsymbol{\omega}_j)]$ between an input sequence of training vectors $\{\mathbf{x}_y, y = 1,2,..., n\}$ and its corresponding output sequence of code vectors $\{\boldsymbol{\omega}_j, j = 1,2,...,c\}$ is defined as

$$D = E[d(\mathrm{x}_y, \omega_j)] = \frac{1}{n}\sum_{y=1}^{n} d(\mathrm{x}_y, \omega_j) \quad (3)$$

The grey relational theory proposed in 1982 [19-20]. Grey relational theory demonstrates the measurement of similarity between training vectors and codevectors based on the grey relational space. Let $\mathbf{x}_y$ be a training vector and $\boldsymbol{\omega}_j$ be the codevector j, then the grey relational coefficient is defined as

$$\gamma_{y,j} \equiv \gamma\left(\mathbf{x}_y, \boldsymbol{\omega}_j\right) = \frac{\Delta_{\min.} + \xi\Delta_{\max.}}{\Delta_{yj} + \xi\Delta_{\max.}} \quad (4)$$

where

$\Delta_{\min.} = \min\left|\mathbf{x}_y - \boldsymbol{\omega}_j\right|$, $\Delta_{\max.} = \max\left|\mathbf{x}_y - \boldsymbol{\omega}_j\right|$, $\Delta_{yj} = \left|\mathbf{x}_y - \boldsymbol{\omega}_j\right|$, and $0 < \xi < 1$ is the distinguished coefficient.

The spread grey-based competitive Hopfield neural network has the same architecture as the competitive Hopfield neural network [9-10]. In order to update the training performance, the grey relation theory was embedded into a Spread Grey-based competitive Hopfield Neural Network (named SGHNN). Therefore the simplified object function for the SGHNN can be modified as

$$E = \sum_{p=1}^{3}\sum_{x=1}^{n}\sum_{y=1}^{n}\sum_{i=1}^{c}\sum_{j=1}^{c} V_{x,i;p}\,\gamma_{y,j;p}\,V_{y,j;p} \quad (5)$$

and

$$Net_{x,i;p} = \sum_{y=1}^{n}\sum_{j=1}^{c} \gamma_{y,j;p} V_{y,j;p} \quad (6)$$

where $\gamma_{y,j;p}$ is the modified grey relational grade between training samples $\mathbf{x}_y$ and codevector $\mathbf{w}_j$ at the pth plane and $\mathbf{I}_{x,i;p} = 0$.

We then map R, G, and B plane training vectors of a color image to the SGHNN neuron array, and using Eqs. (5) and (6), the proposed spread competitive Hopfield neural network in each plane can be used for color vector quantization in a parallel manner are given as follows.

Step 1: Input a set training vector $\mathbf{X}_p = \{\mathbf{x}_{1;p}, \mathbf{x}_{2;p}, \cdots, \mathbf{x}_{n;p}\}$, and the number of class c.

Step 2: Compute the grey relational grade matrix $\mathbf{R} = \{\gamma_{y,j;p}\}_{y=1,j=1;p=1}^{n,c;3}$ with training samples and codevectors at each plane.

Step 3: Set the initial number of the vectors to be n. Each class contains at least one vector.

Step4: Calculate the input to each neuron (x,i) by Eq. (6).

Step 5: Apply the equation below to update the output states for each neuron in a row.

$$V_{x,i;p} = \begin{cases} 1 & if \quad Net_{x,i;p} = \max\{Net_{x,1p}, Net_{x,2p}, \cdots Net_{x,c;p}\} \\ 0 & otherwise \end{cases}$$

Step 6: Repeat Steps 4 and 5 for all rows, and count the number of neurons for the new state. If no neuron is changed go to step 7, otherwise go to step 4.

Step 7: Complete the codebook design in the *p*th plane (p = 1,2,3).

3.2 Interpolative Vector Quantization

Interpolative vector quantization has been devised to alleviate the visible block structure of coded images and lessen the sensitive codebook problems produced by a simple vector quantizer [21]. In a VQ system, the complexity of the encoders is often depending up on the size of the codebook used. In this paper, for the purpose of reducing massive hiding data, the $N \times N$ original image was down-sampled into $\frac{N \times N}{2}$ size image. Therefore, just only $\frac{N \times N}{2}$ pixels of each plane in the original image was processed using the proposed SGHNN approach. Then the interpolative method was used to rebuild the empty pixels using the average of their neighbor pixels in each plane. That is to say, the Interpolative method must do an extra work for interpolating pixels and little rebuilt quality maybe reduced but can reduce massive hiding data.

3.3 Color Image Hiding Through Hadamard Transform

Among various popular image transforms, Hadamard Transform (HT) [22-23] takes the least computation overhead since its basis vectors content only +1 and –1. No multiplication is necessary and only fixed point arithmetic is required for computing the transformation. The forward and inverse 2-D Hadamard transform for an $N \times N$ image can be define as:

Forward:

$$F(u,v) = \frac{1}{N} \sum_{j=0}^{N-1} \sum_{k=0}^{N-1} f(j,k)(-1)^{\sum_{i=0}^{\ell-1} [b_i(u) b_i(j) + b_i(v) b_i(k)]} \tag{7}$$

Inverse:

$$F(j,k) = \frac{1}{N} \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} f(u,v)(-1)^{\sum_{i=0}^{\ell-1} [b_i(u) b_i(j) + b_i(v) b_i(k)]} \tag{8}$$

where $F(u,v)$ are the Hadamard transform coefficients, $f(j,k)$ are the pixel value at (j,k), $N = 2^{\ell}$ for some ℓ, and $b_i(u)$ is the ith bit of u in the binary form.

In our scheme, a 256×256 disguise color image is divided into non-overlapped 4096 blocks (4×4), which are transformed to frequency domain by the HT. The bit stream of indices and sorted codebooks of 256×256 original color image compression based on IVQ is embedded into eight coefficients in lower band of each block [15]. The embedded process each plane is described as follows

Step 1: Sequentially extract out every 8 bits data from bit stream of IVQ indices and sorted codebooks.

Step 2: Obtain a random number, generated by pseudo random number system, which points to one of 4096 blocks of disguise color image.

Step 3: Embed extracted the 8 bits data into the 8 lower band coefficients in the block pointed by Step 2.

Step 4: Repeat Step 1 to Step 3, until all bit stream of IVQ indices and sorted codebooks is run out.

Step 5: The employee replace bit was hidden at position bit 3 in the selected 8 bits coefficient.

The extraction step of original color image from embedded color image is similar to the process of the embedded algorithm. The extraction step is described below.

Step 1: Transform the embedded color image to frequency domain by HT.

Step 2: Use the same set of random numbers, which is applied in the embedding process.

Step 3: Apply the random number to find the extract location of the HT block in the original disguise color image.

Step 4: Extract 8 bits data from each HT block by inverse embedded bit stream of IVQ indices and codebooks.

Step 5: Rearrange IVQ indices and codebooks to original color image.

Step 6: Rebuilt original color image.

4. Experimental Results

Based on the proposed color image hiding method, we developed a SGHNN algorithm to compress color image and HT-based digital watermarking software to color image hiding. The relative compression efficiency and hiding empirical test are shown as follows.

4.1 Compression Efficiency

The codebook design is the primary problem in image compression based on Vector Quantization (VQ). In this paper, the 256×256 original color image was separated into RGB 3-plane. Then each plane were divided into 4×4 blocks to generate 4096 non-overlapping 16-D training vectors, and were trained using the proposed spread GHNN (SGHNN) method to generated better codebook based on VQ. To show the reconstruction performance, the resulting images were evaluated by the average *PSNR* among three-color planes is

$$PSNR_A = \frac{PSNR_R + PSNR_G + PSNR_B}{3} \qquad (9)$$

where $PSNR_R$, $PSNR_G$, and $PSNR_B$ are the *PSNR* for red, green, and blue planes, respectively, and the resulting images were evaluated subjectively by the Peak Signal to Noise Ratio (*PSNR*) that is defined for images of size $N \times N$ as

$$PSNR = 10\log_{10}\frac{255 \times 255}{e^2} \qquad (10)$$

where e^2 is the mean squared of the reconstructed image error and 255 is the peak gray level, respectively. Table 1 shows the *PSNRs* of the “House”, “Girl”, and “couple” images reconstructed from the codebook of size 128 designed by the spread GHNN method each plane. From the simulated results, the proposed SGHNN method can produce good reconstructed color image quality.

4.2 Hiding Empirical Test

To show the feasibility of the proposed color image hiding method, we employed the 256×256 “Couple” color image as our original color image. To camouflage this original color image, we employed the 256×256 "Tree" color image as the disguise color image. Figure 1 displays the experimental results. Pictures in the Figure 1 (a) is the "Couple" original color image, Figure 1 (b) is the "Tree" disguise color image, Figure 1 (c) is embedded "Tree" color image whose average PSNR is 38.8602 dB, and Figure 1 (d) is extracted and reconstructed "Couple" original color image whose average PSNR is 29.0931 dB. Experimental results show that the embedded color image is unobtrusiveness and the extracted and reconstructed color image has acceptable quality.

5. Conclusions and Future Work

In this paper, we present a novel color image hiding technique based on interpolative VQ through a spread grey-based competitive Hopfield neural network and HT-based digital image watermarking embedded process. The goal is to offer secure communication in the internet through compress the original color image into another disguise color image. The presented approach allows color image can be compressed with high compression ratio, and the security of transmission process in the internet is enhanced. Experimental results show that the embedded color image is unobtrusiveness and the extracted and reconstructed original color image has acceptance quality. However, the timing measurements, there is a need to build a hardware system, which exploits parallel processing to speed up the color image hiding. The hardware implementation of SGHNN algorithm will be our future work.

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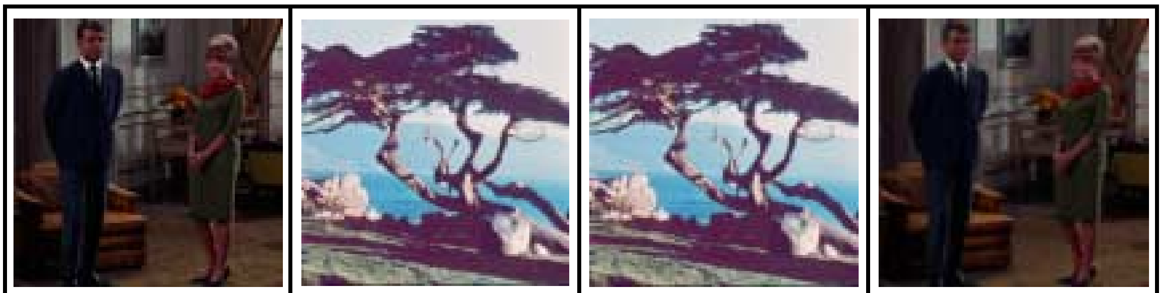
Table 1. *PSNRs* of color images reconstructed by the Spread GHNN (SGHNN) with 128 codevectors each plane.

Plane / Test images	R	G	B	Average
House	31.5357	30.5033	30.6781	30.9057
Girl	29.6354	29.8905	29.7931	29.7730
Couple	30.3423	30.8273	30.8622	30.6773



(a) Original color image | (b) Disguise color image | (c) Embedded color image | (d) Extracted & rebuilt original color image

Fig. 1 Experimental test for the proposed color image hiding

Color Image Hiding Using Neural Networks with Grey Relation Based on Interpolative Vector Quantization

應用插補向量量化之灰關聯神經網路於彩色影像藏密技術

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摘要

本篇論文提出一個應用灰關聯競爭式霍普神經網路與 Hadamard 域數位浮水印技術於彩色影像藏密。目的是使用壓縮原始彩色影像並嵌入另一張偽裝彩色影像以提供安全的網際網路通信。我們的方法包括使用一個植基於插補向量量化之灰關聯競爭式霍普神經網路之彩色影像壓縮技術，然後再利用 Hadamard 域浮水印技術嵌入原始彩色影像插補向量量化之索引值與排序之編碼簿進一張偽裝彩色影像，以至於設計出一套安全可行的彩色影像藏密技術。

關鍵字：插補向量量化 (Interpolative vector quantization)，灰色理論 (Grey theory)，神經網路 (Neural networks)，Hadamard 轉換 (Hadamard transform)。