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A Self-embedding Robust Digital Watermarking Algorithm with Blind Detection

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Abstract: In order to achieve the perfectly blind detection of robustness watermarking algorithm, a novel self-embedding robust digital watermarking algorithm with blind detection is proposed in this paper. Firstly the original image is divided to not overlap image blocks and then decomposable coefficients are obtained by lifting-based wavelet transform in every image blocks. Secondly the low-frequency coefficients of block images are selected and then approximately represented as a product of a base matrix and a coefficient matrix using NMF. Then the feature vector represent original image is obtained by quantizing coefficient matrix, and finally the adaptive quantization of the robustness watermark is embedded in the low-frequency coefficients of LWT. Experimental results show that the scheme is robust against common signal processing attacks, meanwhile perfect blind detection is achieve. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Digital watermarking, Self-embedding, Perfectly blind detection, Lifting-based wavelet transform, Non-negative matrix factorization.

1. Introduction

Existing robust watermarking algorithm in ownership to identify [1-3], usually through the calculation of correlation between original image and extract the watermark for copyright. Copyright process more or less will need to use the original carrier, the original watermark information, cannot achieve real completely blind detection. [4] introduced the embedded technology is put forward a kind of DWT-SVD domain blind robust quantization watermarking algorithm. DWT algorithm to the original image and wavelet low frequency subband is divided into non-overlapping blocks, SVD to each sub-block, by comparing the two adjacent relationship between the size of the largest singular value feature watermark sequence, and then selected from the characteristics of embedded watermark sequence by odd-even quantization rules since the embedded into the original image wavelet low frequency subband largest singular value of each sub-block, finally carries on the SVD was produced from synthesis and IDWT watermark image. The experimental results show that the algorithm has good invisibility and security, and by combining the characteristics of embedded watermark and blind extraction authentication watermark sequences to whole blind detection. But the algorithm exist since the embedding of the watermark image watermark sequence is used to extract characteristics have influence on the maximum watermark sequences, so the extracted watermark sequences and authentication watermark sequences between error, etc. [5] the robust watermark embedding the idea is introduced into the field, and put forward a kind of completely blind detection robust watermarking algorithm. Algorithm, the original image is first divided into non-overlapping blocks, discrete cosine transform to each sub-block, by comparing the dc coefficient of each sub-block and all child block dc coefficient of the relationship between the size of the average characteristics of the watermark, Logistic chaotic sequence is used to analyze the characteristics of the watermark encryption, then adjust each sub-block of low frequency coefficient of discrete cosine transform from 2 since the size of the embedded watermark encryption features, finally to contain the watermark image inverse discrete cosine transform (idwt). Algorithm combining the feature of the embedded encryption watermark and blind extraction authentication watermark realization of completely blind detection. Experimental results show that the algorithm in the resistance to smoothing, noise adding, JPEG compression and shear and geometric attacks such as random sampling, delete rows, partial migration down, shift to the right column shows strong robustness. But the algorithm will have a characteristic of original image each sub-block, watermark is embedded into the DCT coefficients of the block, make the algorithm for vector quantization attack such as poor robustness.

In this paper, we design a wavelet transform based on nonnegative matrix decomposition and ascension of the embedding robust watermark blind detection algorithm. Algorithm firstly carried out on the original image is partitioned subgraph ascension discrete wavelet transform (idwt) low frequency approximation components; Second to make nonnegative matrix decomposition approximation components can approximate the base of sub-block image matrix and the matrix; Then will get the robust watermarking matrix quantitative sequence, the robust watermark sequence adaptive quantization embedded into the original image is low frequency with approximate weight. The experimental results show that the scheme of common signal processing has very strong robustness, robust watermark sequence of completely blind detection is realized.

2. NMF

Given a set of multivariate *n*-dimensional data vectors, the vectors are placed in the columns of an $n\times m$ matrix *V* where *m* is the number of examples in the data set. This matrix is then approximately factorized into an $n\times r$ matrix *W* and an $r\times m$ matrix *H*. Usually *r* is chosen to be smaller than *n* or *m*, so that *W* and *H* are smaller than the original matrix *V*. This results in a compressed version of the original data matrix. The common describe of NMF as follow:

$$V \approx WH , \qquad (1)$$

The Equation (1) can be rewritten column by column as $v \approx Wh$, where v and h are the corresponding columns of *V* and *H*. In other words, each data vector *v* is approximated by a linear combination of the columns of *W*, weighted by the components of *h*. Therefore *W* can be regarded as containing a basis that is optimized for the linear approximation of the data in *V*. Since relatively few basis vectors are used to represent many data vectors, good approximation can only be achieved if the basis vectors discover structure that is latent in the data.

To find an approximate factorization $V \approx WH$ [6, 7], we first need to define cost functions that quantify the quality of the approximation. Such a cost function can be constructed using some measure of distance between two non-negative matrices *A* and *B*. In the NMF literature, two popular cost functions have been studied. The first is the classical Euclidean distance or Frobenius norm, given by

$$\|A-B\|^2 = \sum_{ij}(A_{ij}-B_{ij})^2 , \qquad (2)$$

Another useful measure is

$$D(A\,\|\,B) = \sum_{ij}\left(A_{ij}\log\frac{A_{ij}}{B_{ij}} - A_{ij} + B_{ij}\right) , \qquad (3)$$

The above measure is known as the generalized Kullback-Leibler (KL) divergence. It reduces to the standard KL divergence, or relative entropy, when $\sum_{ij} B_{ij} = 1$ so that the matrices can be regarded as normalized probability distributions.

3. Discrete Wavelet Transform

In numerical analysis and functional analysis, a discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled. As with other wavelet transforms, a key advantage it has over Fourier transforms is temporal resolution: it captures both frequency and location information (location in time).

The DWT of a signal x is calculated by passing it through a series of filters. First the samples are passed through a low pass filter with impulse response resulting in a convolution of the two:

$$y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k] , \qquad (4)$$

The signal is also decomposed simultaneously using a high-pass filter h. The outputs giving the detail coefficients (from the high-pass filter) and approximation coefficients (from the low-pass). It is important that the two filters are related to each other and they are known as a quadrature mirror filter.

However, since half the frequencies of the signal have now been removed, half the samples can be discarded according to Nyquist's rule. The filter outputs are then subsampled by 2 (Mallat's and the common notation is the opposite, g- high pass and h- low pass):

$$y_{low}[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k] \quad (5)$$

$$y_{high}[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n+1-k] \quad (6)$$

This decomposition has halved the time resolution since only half of each filter output characterizes the signal. However, each output has half the frequency band of the input so the frequency resolution has been doubled.

The discrete wavelet transform has a huge number of applications in science, engineering, mathematics and computer science. Most notably, it is used for signal coding, to represent a discrete signal in a more redundant form, often as a preconditioning for data compression. An example of the 2D discrete wavelet transform that is used in JPEG2000. The original image is high-pass filtered, yielding the three large images, each describing local changes in brightness (details) in the original image. It is then low-pass filtered and downscaled, yielding an approximation image; this image is high-pass filtered to produce the three smaller detail images, and low-pass filtered to produce the final approximation image in the upper-left.

3. The Analysis and Design of the Algorithm

Based on previous theoretical basis, the article designed a robust digital watermark embedded blind detection algorithm, the algorithm including the robust watermark extraction, the robust watermark sequences from the embedded testing and certification, the robust watermark sequence extracted watermark sequences, a total of four steps, the following detailed description.

3.1. The Robust Watermark Sequence Extracted

To facilitate the robust watermark sequence extraction, this paper use wavelet low frequency approximation coefficient of the mean as the statistical characteristics. The statistical characteristic from the wavelet coefficients of the approximation, on behalf of the original signal perception is the most important component, to the common signal processing operations has stronger robustness, and due to the high correlation between adjacent pixels, random cutting operations such as even cause larger changes, individual wavelet coefficients will not result in great changes of statistical average. This article designed to extract the core programming

The robust watermark sequence of the design algorithm $\hat{W}$ extraction process is as follows:

1) The original image carrier signal is divided into I L a non-overlapping size is $n \times n$ sub-block $I_i\{i = 0,1,...,L\}$, block number is decided to the number of data elements in the robust watermark sequence $\hat{W}$.

2) In turn to each image sub-block $I_i\{i = 0,1,...,L\}$ class H wavelet decomposition, select sub-block image wavelet low frequency approximation component $C(i)^H_{low}$.

3) The image sub-block low frequency approximation component $C(i)^H_{low}$ NMF decomposition, get the NMF decomposition base matrix of $U_{A(i)}$ and $V_{A(i)}$ coefficient matrix.

4) Coefficient matrix $V_{A(i)}$ block sum $V_{(i)}$, and calculate the average $\bar{V} = Mean(\mathrm{V}_{(i)})$ as a threshold, according to the size of the $V_{(i)}$ in the element and $\bar{V}$ relationship W robust watermark sequences, namely

$$W = \begin{cases} 1, & if \quad V_{(i)} \geq \bar{V} \\ 0, & otherwise \end{cases}, \quad (7)$$

3.2. Since the Embedding Robust Watermark Sequence

The robustness of the design algorithm process description from the embedded watermark sequence is as follows:

1) The original image carrier signal is divided into I L a non-overlapping size for $n \times n$ sub-block $I_i\{i = 0,1,...,L\}$.

2) In turn to each sub-block image $I_i\{i = 0,1,...,L\}$ H class LWT decomposition, select sub-block image wavelet low-frequency approximate maximum component $B(i)^H_{low}$.

3) Robust watermark sequence W scrambling encryption, $\hat{W}'$.

4) According to the watermark embedded quantitative formula, embedding W' quantitative sub-block image wavelet low frequency approximation components,

$$\hat{B}(i)^H_{low} = \begin{cases} (\lambda_i + \frac{1}{2})\delta^i, if & \mathrm{mod}[(\lambda_i + w_i^{'}), 2] = 1 \\ (\lambda_i - \frac{1}{2})\delta^i, if & otherwise \end{cases}, \quad (8)$$

Among them, $\lambda_i = F[B(i)^H_{low} / \delta](i = 1, 2, \cdots, M)$.

5) To embed watermark sequence after wavelet low frequency approximation component reverse LWT transform, get the watermark image I_W .

3.3. The Robust Watermark Sequence Detection

For the inverse process of watermark embedding, watermark detection, this paper designed detection core programming algorithm robust watermark sequence is as follows:

1) Testing end $\hat{I}_W$ will receive an image carrier signal is divided into a non-overlapping L size for $n\times n$ sub-block $\hat{I}_i\{i=0,1,\dots,L\}$.

2) In turn to each image sub-block $\hat{I}_i\{i=0,1,\dots,L\}$ class H LWT decomposition, select sub-block image wavelet low-frequency approximate maximum component $\hat{B}(i)^H_{low}$.

3) According to the type (6) to extract the robust watermark sequence

$$\hat{w}' = \begin{cases} 1 & (\mathrm{mod}(\hat{B}(i)^H_{low},2)=1) \\ 0 & (\mathrm{mod}(\hat{B}(i)^H_{low},2)=0) \end{cases}, \quad (9)$$

4) For $\hat{w}'$. Arnold decryption and reconstruction for $\hat{W}$ watermark sequence.

3.4. Authentication Watermark Sequence Extraction

The authentication watermark sequence W'' extraction process of the design algorithm is as follows:

1) Will receive the image carrier signal segmentation $\hat{I}_W$ as a non-overlapping L size of $n\times n$ sub-block $I_i\{i=0,1,...,L\}$, block number determines the robust watermark sequence is the number of data elements in the $\hat{W}$.

2) In turn to each sub-block image $I_i\{i=0,1,...,L\}$ H level of wavelet decomposition, select sub-block image wavelet low frequency approximation component $C(i)^H_{low}$.

3) The image sub-block low frequency approximation component $C(i)^H_{low}$ NMF decomposition, get the NMF decomposition base matrix of $U_{A(i)}$ and $V_{A(i)}$ coefficient matrix.

4) Coefficient matrix $V_{A(i)}$ block sum $V_{(i)}$, and calculate the average $\bar{V}=Mean(\mathrm{V_{(i)}})$ as a threshold, according to the size of the $V_{(i)}$ in the element and $\bar{V}$ relationship W robust watermark sequences, namely

$$W'' = \begin{cases} 1, & if \quad V_{(i)} \ge \bar{V} \\ 0, & otherwise \end{cases}, \quad (10)$$

5) Calculate $\hat{W}$ and normalized correlation coefficient between W'' (NC) to copyright certification. NC is defined as:

$$NC = \frac{\sum_{i=1}^{N}(\hat{W}\times W'')}{\sqrt{\sum_{i=1}^{N}(\hat{W})^2 \times \sum_{i=1}^{N}(W'')^2}}, \quad (1)$$

4. The Experimental Results

4.1. The Experimental Parameters

Simulation experiment with 512×512 standard gray image Lena, Goldhill, Baboon, etc as the original carrier image, experimental platform using the Windows XP operating system and MATLAB7.0 programming environment, CPU for the Intel Pentium 3 GHz, memory 1 G. Original carrier to Daubchies5/3 grade 1 LWT, of wavelet based wavelet low-frequency subband coefficients of NMF to produce the original characteristics of the watermark sequence. Since the embedded watermark sequence length is 1024 bits. Lena, Goldhill, Baboon 3 image quantization step length is 21.

4.2. Invisibility Experiment

Respectively from two aspects of subjective assessment and objective assessment to measure the invisibility of the algorithm. Fig. 1(a)~Fig. 1(d) as the original standard test images, Fig. 1(f)~Fig. 1(e) for this paper under the algorithm of watermark image. From the experimental results of visible Fig. 1 in this paper, the algorithm has good invisibility of design. Objective evaluation using the Peak signal-to-noise Ratio (Peak Signal to Noise thewire, PSNR), defined as follows:

$$PSNR(I_w, I) = 10\lg\frac{255\times255\times mn}{\sum_{i=1}^{m}\sum_{j=1}^{n}[I_w(i,j)-I(i,j)]^2}, \quad (10)$$

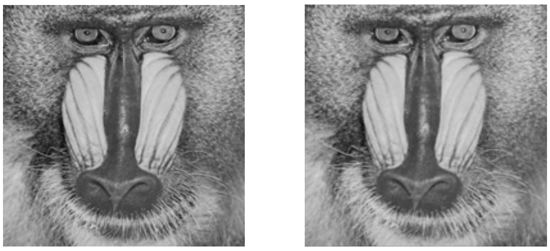
According to this algorithm embedded standard tests before and after the watermark image and the watermark image containing the PSNR as shown in Table 1, listed in Table 1 at the same time the experimental results of document [4]. As it is visible from Table 1, this article and literature [4] algorithm has good visual effect.

(a) The original image Lena

(b) Contain the watermark image Lena PSNR = 47.9506

(c) The original image Goldhill

(d) Contain the watermark Goldhill PSNR = 46.0016



(e) The original image Baboon

(f) Contain the watermark image Baboon PSNR = 42.4377

Fig. 1. The original image and the watermark image sample.

Table 1. Before and after the embedded watermark image PSNR.

Image	PSNR/dB ref. [4]	PSNR/dB in this paper
Lena	41.4827	47.9506
Goldhill	41.1139	46.0016
Baboon	40.8282	42.4377

Literature [4] is a kind of DWT-SVD domain blind since embedding robust quantization watermarking algorithm. Original image carrier of Haar wavelet base 2 levels of DWT, level 2 wavelet low frequency subband split into 2×2 original sub-block to produce feature watermark sequence. Since the embedded watermark sequence length is 1024 bits, the original carrier image with Haar wavelet 1st level DWT, level 1 wavelet low frequency subband split into 8×8 sub-block with the characteristics of embedded watermark sequence, quantization step length is 55, containing three watermark image PSNR is respectively 41.4827 dB and 41.1139 dB and 40.8282 dB. [8] is a grayscale digital watermark algorithm based on singular value decomposition. The size of 64×64 of the 256 level gray image as the original watermark image, block size is 8×8, quantization step length is 48, containing three watermark image PSNR is respectively 41.4663 dB and 41.0269 dB and 40.8878 dB. [9] is a kind of double division and singular value decomposition of digital image watermarking algorithm. The size of 64×64 binary image as the original watermark image, the block size is 8×8, quantization step length 43000, 37000 and 52000 respectively, three pieces of watermark image PSNR is respectively 41.4345 dB and 41.1589 dB and 40.8137 dB.

4.2. Quantization Step Size Selection

The choice of the quantization step length η determines the robustness and invisibility of the algorithm. η is smaller, the algorithm of invisibility, the better, but the worse robustness; η, the greater the algorithm robustness, the better, but not visible. Fig. 2 shows the algorithm in this paper the PSNR and the relationship between the quantization step size curve. 3 images from Fig. 2 shows, when the quantization step length η take 21, this algorithm has good invisibility and strong robustness.

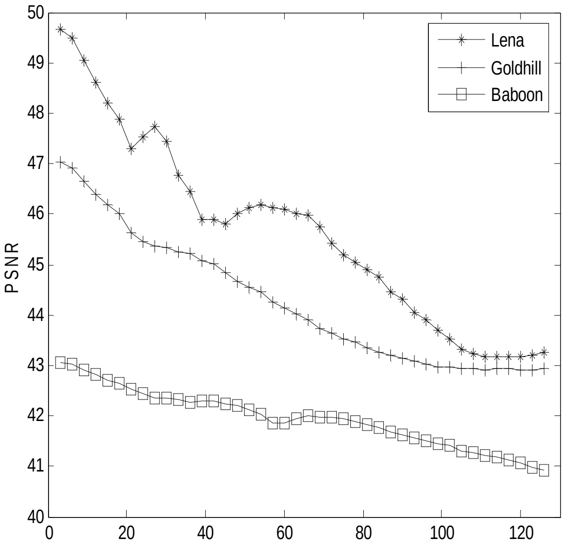


Fig. 3. PSNR quantization step length in relation to the method.

5. Conclusion

In this paper, we design a wavelet transform based on nonnegative matrix decomposition and ascension of the embedding robust watermark blind detection algorithm. Algorithm firstly carried out on the original image is partitioned subgraph ascension discrete wavelet transform (idwt) low frequency approximation components; Second to make nonnegative matrix decomposition approximation components can approximate the base of sub-block image matrix and the matrix; Then will get the robust watermarking matrix quantitative sequence, the robust watermark sequence adaptive quantization embedded into the original image is low frequency with approximate weight. The experimental results show that the scheme of common signal processing has very strong robustness, robust watermark sequence of completely blind detection is realized. This algorithm also has the advantages of simple and easy to implement, which greatly enhances the practicability of copyright protection for digital image works, has a certain application value. Future research will further explore the NMF sequence analysis of the stability and LWT transform coefficient characteristics, set up a more suitable quantization step length, further improve the overall performance of the algorithm, etc.

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