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A Digital Watermarking Algorithm for Color Image Based on DWT

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Abstract

An efficient digital watermark embedding algorithm for color image was presented in this paper, which is based on the discrete wavelet transform (DWT) and the spectral characteristics of human vision system. Firstly, three color separations was performed for color image, and color components of color image were transformed by DWT. Secondly, the embedding position of the watermark was confirmed by comparing the energy value of the low frequency sub-band in the transformed blue component and green component. Thirdly, the watermark was made Arnold Transform for encryption and was embedded in the color component with a larger power. Finally, this paper made the simulation experiments to evaluate the performance of the watermark. The simulation results showed that the embedded watermark had good invisibility and robustness for the common image processing, such as filtering, noise, especially compression and cropping.

Keywords: digital watermarking, color image, DWT, HVS

1. Introduction

In recent years, the network and digital technology has been rapidly developing and low copy-cost and convenient tamper makes a huge impact on the copyright protection of multimedia and greatly damages the interests of the copyright owner.As digital watermarking technology plays an important role on the copyright protection,it becomes the hot spot of the research.

At present, researchers mostly concentrate on the digital watermarking algorithm for gray image [1] or binary image [2]. However, there are few of efficient digital watermarking schemes for color image [3]. Lianshan Liu proposed a new scheme in which the scrambled watermark was embedded in the green component of color image based on the loss smaller energy theory of green component of color image performing JPEG compression,which can only effectively resist JEPG compression and was insufficient in resisting noise,cropping and filtering [4]. Due to human eyes with different sensitive degrees to the three primary colors of color image (red, green, blue), Jin Sun proposed a digital watermarking algorithm for color image which combines the human vision system (HVS) and discrete wavelet transform (DWT) and it proved that the embedded digital watermark in this algorithm has good invisibility and robustness but the capacity against cropping is weak [5].

This paper proposes an efficient digital watermark embedding algorithm for color image based on the DWT for improving the transparency and robustness of the watermark, especially against cropping and JPEG compression. It is known that human eyes are most insensitive to blue of three primary colors in color image as well as the green component can resist JPEG compression and cropping in the HVS. Firstly, three color separation is implemented for a color image. Secondly, the components of this color image make 2-level Discrete Wavelet Transform. Thirdly, we confirms the embedding position of the watermark by comparing the energy value of low frequency sub-bands in the transformed blue component and green component. The experimental results demonstrate the embedded watermark using this algorithm has good invisibility and robustness in the common image processing, such as filtering,noise,especially JPEG compression and cropping.

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2. Watermark Image Preprocessing

Before the watermarking image is embedded ,it should be encrypted in advance, namely made the scrambling transformation in order to ensure the security of the watermarking information and improve the robustness of the original image. The size of the image can not be changed by the scrambling transformation,because the scrambling transformation of digital images is a reversible transformation attained by changing the image pixel position or gray level. There are many common scrambling transformations such as Arnold Transform, Affine Transform, Magic Square Transform and Fractional Hilbert Transform. This paper utilizes Arnold Transform to scramble the watermark for encryption.

Arnold Transform, known as "cat face transform", is a pixel position transformation proposed by Arnold when he studied argotic theory [6]. Arnold Transform changes the pixel location of the image by matrix operations. The formula of Arnold Transform is as follows:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \bmod N = C \begin{bmatrix} x \\ y \end{bmatrix} \bmod N \qquad x,\ y \in (0,1,2,\ \ldots,\ N-1) \tag{1}$$

Where (x, y) denotes the original image pixel, (x ', y') denotes the transformed image pixel, N denotes the image's order and N is also the image's size because Arnold Transform is often used to square images.

The basic idea is that the point (x,y) in the original image is as the initial value and the transformed position (x ', y') is obtained through matrix operations,then the transformed position is calculated one by one. The image completes Arnold Transform once after N^2 time matrix operations. According to the determinant |C|=1 of transformation matrix C, this scrambling transformation is a transformation preserving area by which the size of the image can not be changed and is also a one-to-one mapping by which each pixel of the image can only be transformed to its another pixel.

Arnold Transform has a periodicity. With increasing of transformation frequency K, the image becomes more and more disordered and gradually disrupts the correlation among pixels of the original image; when K increases to its period T, the image is restored to the original image. The transformation frequency K is the key. To restore the original image from the scrambled image, it is necessary to make T-K times Arnold Transform for the image. Figure 1 shows the gray image "TJFECS" when N=64 and the watermark image after K=20 Arnold Transform.

Figure 1. The Original Watermark and the Scrambled Watermark using K = 20 Arnold Transform

3. Watermark Embedding

3.1. Discrete Wavelet Transform (DWT)

Discrete Wavelet Transform is a time/frequency analysis algorithm which has the characteristic of multi-resolution analysis. It not only analyzes signals in the time domain or frequency domain but in the combined domain with time and frequency so that the signal has a good frequency resolution in the low frequency sub-band and a good time resolution in the high frequency sub-band.

Discrete Wavelet Transform for two-dimensional image is to perform multi-resolution decomposition for the image, which decomposes the image into the low frequency sub-band and the high frequency sub-band whose resolutions are different. The main energy of the image is accumulated in low frequency sub-band where records the feature information of the image.

The low frequency sub-band is the best approximation to original image with maximum scale and minimum resolution after wavelet transformed. The high frequency sub-band including horizontal, vertical and diagonal cotains less energy and its sub-band records the image's details and texture information. The results of performing 2-level DWT for a N × N image is shown in Figure 2.

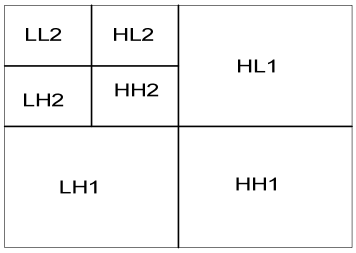


Figure 2. 2-Level DWT Transform for N×N

After the image is made 2-level DWT, seven sub-bands can be obtained: LL2, HL2, LH2, HH2, HL1, LH1, HH1, as shown in Figure 2 where LL2 is the low frequency sub-band and the rest are the high frequency sub-bands. The bigger the wavelet decomposition level is, the lower the frequency sub-band resolution is and the more important the wavelet coefficient is. The importance degree from high to low is: LL2, HL2, LH2, HH2, HL1, LH1 and HH1.

The digital watermarking algorithm based on the DWT has following advantages such as a big watermark embedding capacity, good robustness against adding noise and cropping attacks, standards compatibility with JPEG compression and the combination with the human vision system. Therefore, this digital watermarking algorithm becomes one of the hot issues in current research.

3.2. Watermark Embedding Positions

According to the spectral characteristics of human vision system (HVS), it is known that human eyes have different sensitivities for different colors. For the three primary colors which make up color image (R, G, B), human eyes are the most sensitive to green (G) and the least sensitive to blue (B).

For that,the standard spectral intensity function [7] is definited by Hai Tao as follows: a pixel brightness Y = 0.299 R + 0.578 G + 0.144 B. The robustness of the embeded watermark is reduced for the energy value of the blue component and red component after color image is croped or JPEG comprossed. The watermark emdeded in these components is easily lost and is fully extracted difficultly.

However, the energy in the green component loses less and the watermark embedded in the green component has good robustness against cropping and JEPG compressing. There are respective advantages and disadvantages in embedding the digital watermark in each component: the watermark embedded in the blue component with greater embedding strength has better transparency and robustness against lowpass filtering, Gaussian or salt & pepper noise, but it is weak against geomorphing and JPEG compressing; the watermark embedded in the green component has a better capacity against geometric attacks such as cropping,scaling and JPEG compressing and the embedding strength should be reduced to ensure the good invisibility of watermark system.

By analyzing the Discrete Wavelet Transform theory in part 2 of this paper, it can be known that high frequency sub-bands (HLi, LHi, HHi, (i = 1, 2)) denote the image's edge and texture after 2-level DWT. The watermark embedded in the high frequency sub-bands doesn't affect the quality of carrier images and has good transparency in the light of the masking characteristics of human vision system.But the watermark embedded in the high frequency sub-bands can be easily lost because it contains rarely part energy of the image. Low frequency sub-band (LL2) where the robustness of embedded watermark is very strong focuses most energy of the image.But the embedding strength of the watermark in low frequency sub-band shouldn't be too strong for the sub-band represents the smooth part of carrier image and human eyes are very sensitive to the changes of sub-band.

Considering the transparency and robustness of watermarking system, this paper refer to embed the watermark in low frequency sub-band of the blue and green component of static color image after the components are made 2-level DWT, where the embedding strength of the blue component is stronger than of the green component.

3.3. Watermark Embedding Process

The model of watermark embedding is shown in Figure 3.

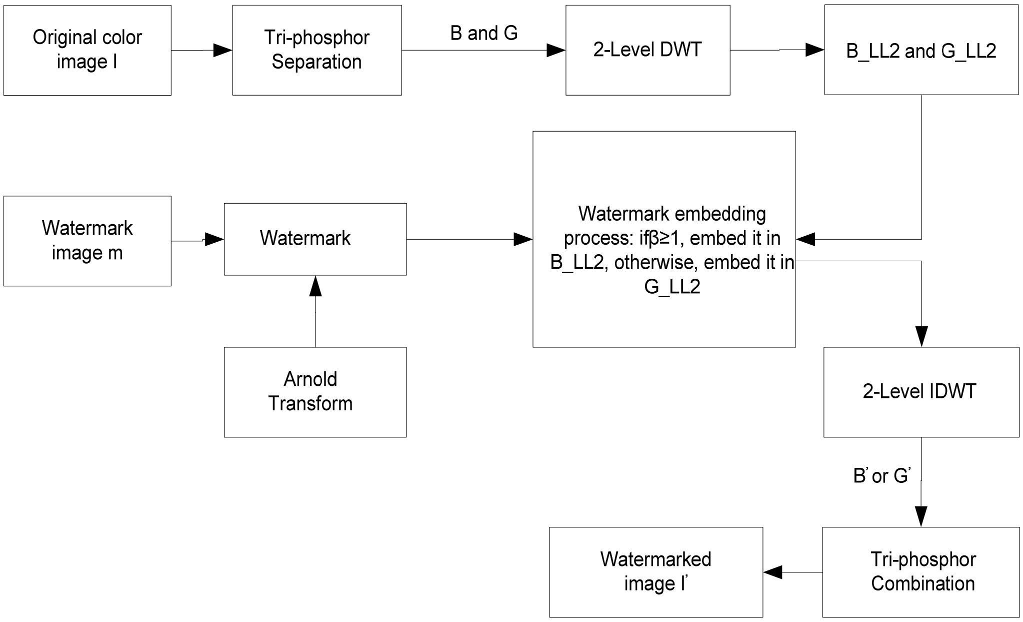


Figure 3. Digital Watermarking Embedding

A $M \times M \times 3$ color image I is as the original carrier image,and a $N \times N$ gray image m($N \leq M / 4$) is as the watermarking image. The major steps involved in the watermark embedding are as follows:

(1) Three Color Separation.The color image is decomposed into three color components and the watermark is selectively embedded in the blue component and green component of the carrier image. Namely, I is decomposed into three two-dimensional $M \times M$ color components: red (R), green (G), blue (B).

(2) Discrete Wavelet Transform.Respectively the components G and B of I are performed 2-level Wavelet Transform and the corresponding low frequency sub-bands can be obtained, their low frequency sub-band coefficients are G_LL2, B_LL2.

(3) Arnold Transform. The cycle T of Arnold Transform for a N order image is calculated by the formula (1). The watermarking image m is performed $K < T$ times Arnold Transform where K is the key. Eventually, the scrambled watermark w embedded in I is achieved.

(4) 2-Level DWT.The energy values E of G_LL2 and B_LL2 are calculated by the formula (2), and their ratio is β: β= E (B_LL2)/E (G_LL2): if β≥1, the watermark is embedded in B_LL2; otherwise, it is embedded in G_LL2. The digital watermarking embedding formula is shown as formula (3). The calculation formula of energy value of the low-frequency sub-band E is:

$$E = \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N} X^2(i, j) \tag{2}$$

Where N denotes the low frequency sub-band size of color component after wavelet transformed, X (i, j) denotes the position coefficient of the low-frequency sub-band (i, j).

Digital watermarking embedding formula is:

$$LL'(i, j) = LL(i, j) + \alpha \times w(i, j) \tag{3}$$

Where LL(i, j) denotes the low frequency sub-band coefficient of original image after DWT, LL'(i, j) denotes the coefficient of low-frequency sub-band which is embedded the watermark, α denotes the embedding strength of digital watermark, w (i, j) denotes the pixels of watermark point (i, j). In the simulation experiment of this algorithm, the embedding strength of B is B_α=0.1, and the embedding strength of G is G_α = 0.08.

(5) 2-Level IDWT.The low frequency sub-band and the corresponding original high frequency sub-band in the B or G where the watermark is embedded is performed 2-level wavelet transform, and then B' or G' can be obtained.

(6) Tri-phosphor Combination.The original image I and the new components B' and G' are performed tri-phosphor combination and the embedded watermarking color image I' is formed.

4. Simulation Experiments and Performance Evaluation

4.1. Performance Evaluation Indexes of the Algorithm

Digital watermarking embedding algorithm often uses these indexes to evaluate as follows.

(1) Peak Signal Noise Ratio (PSNR). PSNR is used to compare the difference of the original image and the watermarked image: The bigger the PNSR value is,the smaller the difference between the original image and the watermaked image is and the better the watermarking transparency is. For a $\mathrm{M} \times \mathrm{N}$ two-dimensional image,the computation formula of its PNSR is as follows:

$$\text{PNSR} = 10 \log_{10} \frac{I_{\max}^2(i, j)}{\frac{1}{M \times N}\sum_{i=1}^{M}\sum_{j+1}^{N}(I(i, j) - I'(i, j))^2} \tag{4}$$

Where I (i, j) denotes the pixel value of the original image (i, j) , I' (i, j) denotes the pixel value of the watermarked image.

(2) Normalized Correlation (NC).Normalized Correlation is used to measure the robustness of the digital watermarking embedding algorithm and to compare with the similarity of the original watermark and the extracted watermark. Among NC∈[0,1], the bigger the NC is, the more similar the original image and the extracted watermark are. When NC=1, the original image is identical with the extracted watermark. For a $\mathrm{M} \times \mathrm{N}$ two-dimensional image, the computation formula of its NC is as follows:

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} w(i, j) \times w'(i, j)}{\sum_{i=1}^{M}\sum_{j=1}^{N} w(i, j)^2} \tag{5}$$

4.2. Simulation Experiments

Our proposed scheme uses MATLAB 7.0 in simulation experiments.In the experiments, $256 \times 256 \times 3$ color images "Lena" and "Baboon" are as host images and a 64×64 gray image

"TJFECS" is as the watermarking image. After the images is embedded the watermark, the results of experiments about the transparency of watermark system are clearly illustrated in Figure 4 and Figure 5.

Figure 4. Host Image (a), Watermark (b), Watermarked image (c), Extracted watermark (d) (PNSR = 29.64, NC = 0.9986)

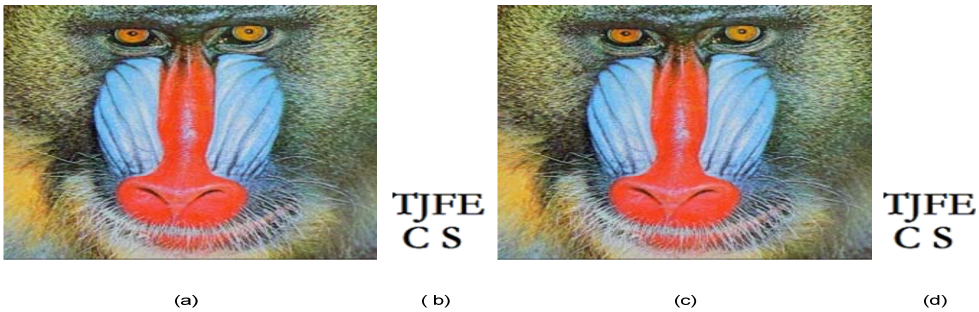


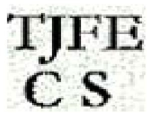
Figure 5. Host Image (a), Watermark (b), Watermarked image (c), Extracted watermark (d) (PNSR =31.22, NC = 0.9995)

In order to measure the robustness of watermark system using this embedding algorithm, the watermarked image Lena is made the resistance attack test.By all kinds of attacks, the extracted watermarks are shown in Figure 6.

(a) 3×3 Median filter (NC=0.9412)

(b) Adding d =0.01 salt and pepper noise (NC=0.9375)

(c) Adding variance 0.002 Gaussian noise (NC=0.9883)



(d) QF = 40 JPEG Compression (NC=0.9583)

(e) 1/4 Cropping (NC=0.9153)

(f) Image Sharpening (NC=0.9410)

Figure 6. Extracted Watermark from Watermarked Images through All Kinds of Attacks

From the Figure 5, the NC values of the extracted watermarks from the watermarked image after all kinds of attacks are all greater than 0.9, and the watermark can be almost completely extracted, showing the strong robustness. The performance of our proposed algorithm is compared with that of the algorithm in [7] against all kinds of attacks and the results are shown in Table 1.

Table 1. The Results of Comparing the Performance in our Proposed Algorithm and the Algorithm in [7]

Attack Type	Our Proposed Algorithm	Algorithm in [8]
Median filtering(3×3)	0.9549	0.9726
Salt-pepper noise(d=0.05)	0.9424	0.9193
Gaussian noise(d=0.003)	0.9603	0.9051
Cropping 1/4 (lower right)	0.9153	0.8639
JPEG Compression(Q=60)	0.9720	0.9551
Rotation 60°	0.7744	0.8462

One can see in Table 1, the watermark using our proposed algorithm has stronger robustness against cropping and JPEG compressing than that the wartermark is embedded partly in blue component and partly in green component. Therefore, the algorithm in this paper is more efficient.

5. Conclusion

This paper proposes an efficient watermarking embedding algorithm for color image which combines the spectral characteristics of HVS and the characteristics of green component in color image. The result of simulation experiments demonstrates that the digital watermark embedding position, which is comfirmed by comparing the low frequency energy value of blue component and green component,not only can avoid the blue component losing more energy in JPEG compression but also can improve the transparency of digital watermark. However, our proposed algorithm is weak to robustness against rotating.

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