

An Adaptive Blind Watermarking Algorithm for Color Image

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Abstract

This paper proposed a novel blind color digital watermarking algorithm based on Integer Discrete Wavelet Transform (IDWT) and Human Visual System (HVS). Firstly, color watermark image was processed into one dimension digital information, and color host image was converted into YIQ color space. Then, according to the features of HVS, encrypted watermark was embedded adaptively into the Y luminance component of the YIQ color space in IDWT domain. The proposed algorithm allowed extracting watermark without the help of original watermark and host image. Experiment results show that the embedded watermark is invisible and robust against common image attacks.

Keywords: image watermark, double-color image, integer discrete wavelet transform, human visual system

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1. Introduction

In recent years, the research of digital image watermarking technology has made great progress, especially the application of grayscale image has been presented many watermarking algorithm such as the spatial domain, transform domain, based on statistics, and based on the physiological model [1-5]. Reference [6] considered the characteristic of Human Visual System (HVS), using YCbCr color space, and embedded gray image watermark into the brightness of low-frequency components Y channel system. Reference [7] adjusted watermark embedding strength according to the regional characteristics of image. Reference [8] proposed an adaptive watermarking algorithm based on HVS, using the brightness of the visual system which has texture masking and watermark masking that can adjust watermark strength. Although reference [9] studied the color watermark embedding into grayscale image, i.e. the host image was not the color. And In [10], a DCT domain technique was presented for color images, which utilized the relations between RGB and YUV models to hide the binary image watermark to color image, which was one of the digital watermarking research fields, but the original watermark image was not color.

The reasons for few watermarking algorithm with color image are:

- 1) Color image contains a lot of information, which embedded may cause the distortion of the original image;
- 2) The watermark distortion is relatively complex, relating with red, green and blue components;
- 3) The embedded watermark is relatively smaller amplitude information, to difficult ensure the robustness. Since it is very meaningful, intuitive, rich, and vivid, the color image watermark is of irreplaceable advantages than other types. If it was breakthrough which has great theoretical significance, therefore it is necessary to have a research of watermarking based on color image watermarking algorithm.

On the basis of color space transformation, this paper proposes a method based on integer wavelet transform for color watermark, which adaptively embed the color watermark into the component Y of the host image, and when the watermark extraction does not need the host image or the original watermark. Its particularities lie in:

- 1) The host image transformed from RGB color space into YIQ color space, using its brightness component Y for convenient to embed watermark;
- 2) Using integer wavelet transform with fast proceed, it does not exist rounding errors;

- 3) Based on the characteristics of HVS and texture masking, it is compromising the contradiction of the invisibility and robustness. Experimental results show that the color watermark has good hidden property, and has strong robustness under the common processing operations of images.

2. Integer Wavelet Transform

In the late 1990s, a new viewpoint about the structure of wavelet was proposed, the so-called integer wavelet lifting scheme, also known as the second generation wavelet transform. Integer lifting wavelet format has truly reversible, which can not consider boundary effect. Compared with the traditional wavelet, lifting scheme basically has the following advantages:

- 1) Owing to completely based on the spatial domain, it is faster and saves more storage space;
- 2) Analyzing spectrum need neither the concept of translation and expansion nor the Fourier transform;
- 3) Mapping directly an integer to another integer without quantization.

Lifting wavelet transform mainly includes three steps as follows:

Step1: Dividing. The original signal C_k^j is divided into even sequence and odd sequence by Eq. (1).

$$C_k^{j-1} = C_{2k}^j, D_k^{j-1} = C_{2k+1}^j \quad (1)$$

Step2: Predicting. Remain unchanged in even sequence and predict the odd sequence with different methods, finally, take the different number between the odd sequence and prediction of the as the next high-frequency coefficients, i.e.

$$D_k^{j-1} = C_{2k}^j - P(C_k^{j-1}) \quad (2)$$

where P represents prediction operator. In the construction of the prediction operator needs to consider the original signal structure features to reflect the relation between the data.

Step3: Updating. Using Eq.3 to update the even sequence, where U is the updating coefficient.

$$C_k^{j-1} = C_{2k}^j + U(D_k^{j-1}) \quad (3)$$

3. The Proposed Algorithm

3.1. The Pre-processing of Color Digital Watermark

A color image, viewed as digital watermark, its digital processing is very important which will directly affect the quality of the embedded digital processing before it is embedded. Its digital processing is more complicated than the one of the binary image. The process of digital watermark image includes many steps as follows:

Step 1: Decomposition of watermark image. Set the watermark is $M \times N \times 24$ (where $M=N=64$) for 24 bits of color image, decomposing watermark into R, G, B three layers, and each layer for two-dimensional matrix size of $M \times N$.

Step 2: Compression of watermark image. The main problem is the amount of data in the progress of color watermarking embedding watermarking. In order to solve this problem, the image compression techniques are used to reduce the data quantity of watermark. The three layers R, G, B must be divided into sub-blocks by 8×8 , and each sub-block should be transformed by DCT. And then only remain a quarter of the top-left corner of DC and AC coefficient areas, abandoning other coefficients. Finally, the DCT coefficient matrix will be compressed from 8×8 pixels to 4×4 ones.

Step 3: The digitalization of watermark image. R, G, B layers are corresponding to the same position 8×8 pieces by Step 2 processing, which will transformed the two-dimensional matrix information into a one-dimensional bits flow.

Step 4: Scrambling of watermark image. In order to make the watermark image keep robustness in the shearing process, this paper uses one-dimensional pseudo random sequence method, using the key to distribution of the watermarking sequence of information. After the above mentioned operation, the original color watermark image $W = \{w(m, n), 0 \leq m < M, 0 \leq n < N\}$ converted into a binary sequence $X = \{w_k, 0 \leq k < 3N_w, x_k \in \{0,1\}, N_w = M^2 \times N^2 / 2^{13}\}$.

3.2. Embedding Digital Watermark

The embedding procedure is shown in Figure 1. The detailed procedures are described as follows.

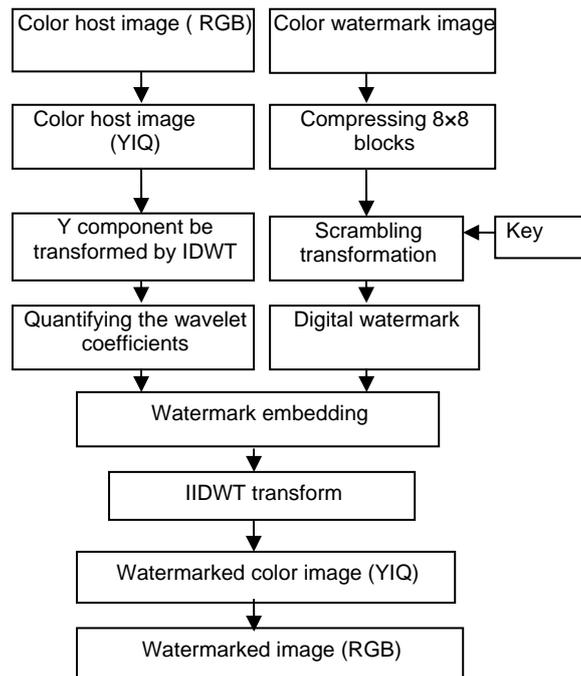


Figure 1. The procedure of embedding watermark

3.2.1 Adaptively determine the embedding location

In order to improve the robustness of color watermark image, the digital watermarking embedding location of the wavelet coefficient is determined adaptively by the HVS. The detailed steps are listed as follows.

Step 1: The color image is transformed from RGB color space to YIQ color space. Their brightness components Y was extracted, transformed by 3-levels integer wavelet transform, and a series of different resolution and different direction sub-bands are obtained.

Step 2: The brightness factor $L(l, \theta, x, y)$ of wavelet coefficients $C(l, \theta, x, y)$ is computed, where $l \in \{1, 2, 3\}$ represents wavelet decomposition layers, and $\theta \in \{LL, LH, HL, HH\}$ represents wavelet transform band direction, and x, y represent wavelet coefficients position. Generally, the coefficients of sub-band present the average energy of image blocks, the greater the value, the higher the brightness of the image block. The brightness factor $L(l, \theta, x, y)$ is defined in Eq.(4).

$$L(l, \theta, x, y) = 1 + \text{abs}(\theta(x, y) - \text{mean}(\theta)) / \text{mean}(\theta) \quad (4)$$

where $\theta(x, y)$ is the coefficient of coordinates is (x, y) in the corresponding band, $mean(\theta)$ is the average coefficient of the corresponding sub-band, and $abs(.)$ is an absolute function.

Step 3: The important coefficients in visual are chosen for watermark embedding. Brightness factor $L(l, \theta, x, y)$ are descending sorted in all of the wavelet coefficients, choosing front $3N_w$ wavelet coefficients $C_k (k = 0, 1, \dots, 3N_w - 1)$ as digital watermarking embedding positions.

3.2.2. Determining the Adaptive Quantization Step

Invisibility is a basic feature of digital watermarking requirement, thus watermarking algorithm must be adapted to human sensitivity. Using the HVS to determine the characteristics of watermark embedding strength can ensure watermark invisible basis effectively improving the robustness. For embedding method based on quantified image watermarking, the selection of quantization step length Δ is very important. The Δ is closely related with the embedding strength, the bigger of Δ , the better of digital watermarking robustness, but also more easily to make image into distortion. For the same image, the different local area has different noise sensitivity, especially, which can cause a bigger distortion on smooth area. And according to the HVS, human eyes has a low sensitivity for the changes of complex regional texture, therefore the larger strength watermark can be embedded without causing visual distortion. If the same Δ value is used in the whole picture, when the value is small, the anti-attack of watermark will be influenced, contrarily, when the value is larger, the image quality will be influenced. What's more, different image needs to adopt different Δ so that it can achieve their good effect. Thus, they need to know the value of Δ in advance when they test every image, which could not realize blind detection completely. Therefore, an adaptive quantization, according to the image of the neighborhood characteristics to determine the Δ value, is undoubtedly the methods to solve the problems.

This paper is based on JPEG2000 image compression scheme, combining with the carrier image neighborhood properties to determine the quantization step length Δ , the quantization step length Δ is determined by Eq.(5).

$$\Delta(x, y) = \ln(\sum |C(l, \theta, x, y)|/2) \quad (5)$$

Obviously, for texture complex areas of the original host image, the quantify wavelet coefficients in the same level decomposition of adjacent position on the corresponding wavelet coefficients are bigger, they should be relatively large quantization step length Δ , so as to realize the adaptive of the embedding strength and regional characteristics. At the same time, logarithmic will transform the exponential increase of wavelet coefficients into linear increase, which will bring the smaller distortion and more correspond HVS. The main factor of affecting algorithm robustness is the change of the wavelet coefficients $C(l, \theta, x, y)$ and quantization step length Δ in various possible attacks. To improve the robustness, we can use neighborhood mean instead of a single wavelet coefficients for estimates and quantification. Set the $N \times N$ neighborhood is chosen to embed, we will selected the quantitative step length

$$\Delta(x, y) = \ln(\sum |C(l, \theta, x, y)|/2N^2) \quad (6)$$

3.2.3. Embedding Watermark by Quantization Wavelet Coefficients

The watermark bit is embedded by quantifying the wavelet coefficients. Let C_k represent the original wavelet coefficient, C'_k represents quantified wavelet coefficient, x_k

is watermark bit, and $x_k \in \{0,1\}$. The process of embedding watermark is described as follows:

Step 1: The definition of quantization rules. The wavelet coefficients C_k is quantified by Eq. (7).

$$Q(C_k) = \text{mod}(\text{floor}(C_k / \Delta), 2) \quad (7)$$

If $\text{mod}(\text{floor}(C_k / \Delta), 2)$ is an odd number, $Q(C_k)$ takes 1, i.e. C_k belongs to 1 class; Otherwise, $Q(C_k)$ takes 0, i.e. C_k belongs to 0 class.

Step 2: Embedded watermark information. Modifying the selected visual important wavelet coefficients C_k , and embedding into watermark information. If $Q(C_k)$ is equal with x_k , then not to modify C_k ; else C_k be modified by Eq.(8).

$$C'_k = \begin{cases} C_k - \Delta & , \text{ if } C_k \geq \Delta > 0 & 0 > C_k > -\Delta \\ C_k + \Delta & , \text{ if } \Delta > C_k \geq 0 & 0 > -\Delta \geq C_k \end{cases} \quad (8)$$

3.2.4. Restoring Watermarked Image.

Using wavelet coefficients C'_k with digital watermarked information instead of C_k and combining the unmodified wavelet coefficients getting 3-level integer wavelet inverse transformation, it can get the gray image Y' containing watermark information, which will combined the component I and Q together transforming from YIQ color space to RGB color space, so as to obtain the embedding watermark color image I' .

3.3 Based on Greedy Algorithm for Knowledge Reduction

The core idea of greedy algorithm is that making the best choice in the current opinion when solving the problem. This algorithm obtains the optimum solution through the initial state and after a number of greedy selection. Each choice of Greedy algorithm is the optimal selection of each step. Its main method is top-down and iterative to make successive greedy choice. After each greedy selection, the original problem can simplified as smaller similar sub-problems comparing to the previous scale. The basic idea of using the greedy algorithm for solving as follows:

1. A mathematical to describe the problem;
2. Solving the problem into several sub-problems;
3. Solving each sub-problem in turn to get the local optimal solution of sub-problems.
4. Synthesizing the local optimal solution of sub-problem into a solution of the original question.

The advantages of the greedy algorithm is that the data discretization method based on the greedy algorithm can identify the property breakpoints under the premise of ensuring the no-distinguish relationship of system does not change. Attributes reduction method based on the greedy algorithm also can extract the important condition attributes from the sample set to achieve the attributes reduction of decision-making table. The idea of the algorithm is clear and easy to describe by using computer language.

3.3. Digital Watermarking Extraction

The watermarking extraction is decided by the method which was inverse process of watermark embedding. It needs not the original image watermark during extracting the color watermark image. Watermark extraction algorithm is shown in Fig.2 .The specific color digital watermark extractions are as follows:

Step 1: Converting watermarked image I' from RGB color space to YIQ color space, extracting chrominance component Y' and implementing 3-level integer wavelet transform.

Step 2: Choosing adaptively visual important wavelet coefficients C_k^* ($k = 0, 1, \dots, 3N_w - 1$).

Step 3: Using the following Eqs. (9) and (10) to extract the watermark information x_k^* .

$$Q(C_k^*) = \text{mod}(\text{floor}(C_k^* / \Delta), 2), \quad (9)$$

$$x_k^* = Q(C_k^*) (0 \leq k < 3N_w) \quad (10)$$

Step 4: Following the opposite operation of the color watermark pre-processing with key to extract the binary sequences $X^* = \{x_k^*, 0 \leq k < 3N_w, x_k^* \in \{0, 1\}\}$.

Step 5: Converting to color watermark image and get R, G, B information with the length of N_w , the information in each 8x8 sub-block containing the watermark corresponding information of R, G, B levels.

Step 6: Transforming 8x8 sub-block by IDCT in each level, restoring this sub-block of R, G, B levels, and get the final extracted watermark.

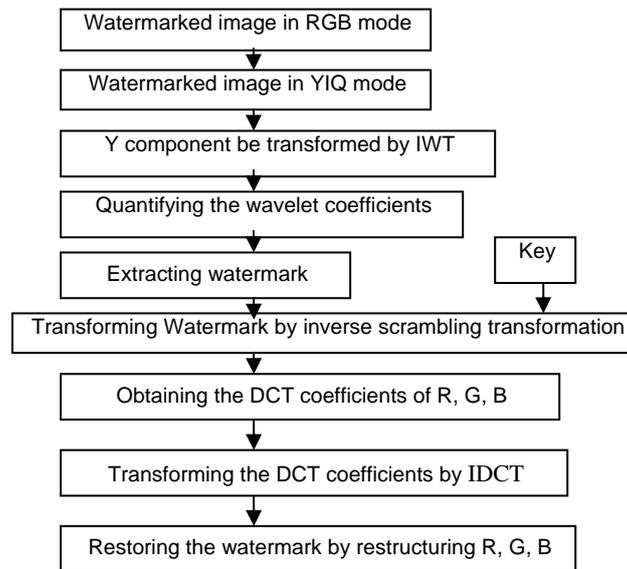


Figure 2. The procedure of extracting watermark

4. Experimental Results

In order to eliminate the influence of subjective factors and embody the impartiality of copyright protection, except through visual to determine, this paper uses the Peak Signal-to-Noise Ratio (PSNR) ($PSNR = MN \max_{m,n} I_{m,n}^2 / \sum_{m,n} (I_{m,n} - I'_{m,n})^2$) to measure similarity degree

between the watermarked color image with the original color image, and adopt the Normalized-correlation-Coefficient (NC) ($NC = \sum_{m,n} (I_{m,n} * I'_{m,n}) / \sum_{m,n} I_{m,n}^2$) to quantitative analyzing the

similarity between the extracted watermark image and the original watermark image.

In order to verify the validity of the algorithm, we make some simulation experiments based on some standard images. In this paper, we take the 512x512x24 bits true color images Peppers, Lena (Figure 3) (a)) as the original host images, and 64x64x24 bits true color image "Lu dong University" school logo (Figure 3 (b)) as a color watermark image.



Figure 3. The Original image and the watermark image
(a) Original image (b) Original watermark

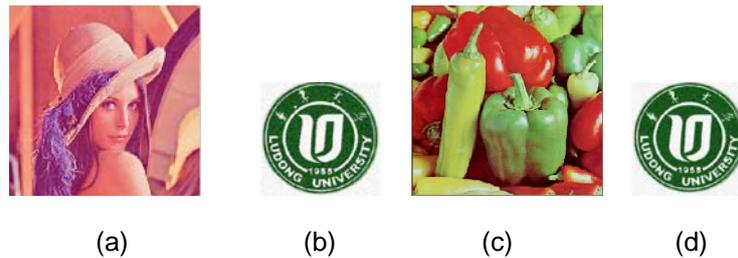


Figure 4. The result of watermark embedding and extracting
(a) Watermarked image (PSNR=41.19dB) (b) Extracted watermark from (a) (NC=0.98)
(c) Watermarked image PSNR=45.16dB (d) Extracted watermark from (c) (NC=0.99)

4.1. Invisibility Testing.

Figure 4. (a), (c) are the watermarked color images, and Figure 4 (b), (d) are extracted color watermarks from Figure 4. (a), (c), respectively, under no-attacks. The results show that the algorithm can embed the color digital watermark into color image, and that concealment effect is perfect. Eyes cannot feel the any difference between the watermarked image and the original image.

4.2. Robustness Testing.

Generally, the attack methods to watermarked image include JPEG compressed, adding noise, geometric cut and smooth filtering, etc. Table 1 gives the robustness experimental results of this paper from anti-attack JPEG compression. The results show the original color watermark image process by DCT that adapting to the characteristics of JPEG compression, so that the robustness is better. Table 2 shows the resistance capability of the watermark algorithm in this paper for dealing with common processes and attacks. The results show that the algorithm based on HVS to locate the embedding positions and adaptive wavelet coefficients quantification is feasible, and the algorithm is strong against other attacks.

Table 1 Experimental results of robustness from anti-attack JPEG compression

Quality coefficient	Lena		Peppers	
	NC	PSNR	NC	PSNR
80	1	37.0	1	31.4
70	1	35.9	1	29.4
60	1	35.1	1	28.1
50	1	34.4	1	27.2
40	0.99	33.8	1	26.4
30	0.97	33.0	0.99	25.4
20	0.88	31.9	0.85	24.3
15	0.68	30.9	0.68	23.6

Table 2 Experimental results of robustness from some common attacks (NC)

Attack operations	Processing parameters	Lena	Peppers
Adding noise	Salt & Pepper	0.95	0.97
	Speckle	0.98	0.99
	Gaussian	0.91	0.92
Compression	Ratio7.2	0.90	0.91
Cropping	A quarter	0.88	0.89
Smoothing	Low-pass filter	0.92	0.93
	Median filter	0.96	0.95

5. Conclusion

In this paper, a new adaptive color watermarking algorithm is proposed. Its main feature is that the host image is transformed from RGB color mode into YIQ color mode; meanwhile, using IDWT and HVS, the watermark position is selected by self-adaption, thus the watermark has good invisibility by color image watermark embedding to the brightness Y of the host image. Through the quantification of wavelet coefficients to improve the color watermarking robustness, extracting watermark does not need the original image. In the future, the problem that whether using Q component to embed part watermark when watermark information-heavy may be further studied.

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