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SVD-based Color Image Watermarking Using Discrete Wavelet Transform

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Abstract. For invisibility and robustness are difficult to reconcile, a combination of singular value decomposition (SVD) and the discrete wavelet transform (DWT) of the color image adaptive watermarking algorithm is proposed. In the embedding process, modification of the singular value of *LL* band and *LH* band exploited to the watermarking scheme which excellent preserves the quality. The additional advantage of the proposed technique is taking advantage of HVS which can adaptively regulate the watermark embedding strength. Experimental results show that the algorithm not only has better transparency, but also has good robustness such as noise, compression, filtering, cropping.

Introduction

Recent years, digital watermarking has become a widely concern hotspot, mainly because it can serve as a tool for copyright protection of multimedia data. An important issue in research of watermarking is the compromising between imperceptibility and robustness [1]. On this issue, human visual system (HVS) model provides a better solution, studies show that the use of visual models to determine the modulation associated with the image mask [2], such as texture, edge and luminance masking, and then use it to insert the watermark, not only has good imperceptibility but also strong robustness [3].

Digital images are an important class of digital products, and the color images occupy a dominant position, however ,some of the mature algorithm in gray image watermark [4-5] don't suitable for directly applied in color images, even if the host image is color, also extract its brightness information or use monochrome channel information for embed. Such as Jianping Lv, who use the information that the human eye is less sensitive to blue then by modifying the blue component of each pixel in watermark embedding [6]. The proposed algorithm can embed watermark into three color channel to improve the watermarking embed capacity, what's more, the use of HVS can adaptively regulate the watermark embedding strength, so as to enhance robustness and ensure transparency.

Human Visual System

HVS depends on three main components [7], frequency sensitivity, luminance sensitivity, and contrast masking. To take how sensitivity to noise changes depending on the band (in particular depending on the orientation and on the level of detail) into account, we let

$$F（r,s）=\begin{Bmatrix}\sqrt{2}, if, s = HH \\ 1, otherwise\end{Bmatrix} * \begin{Bmatrix}1.00 \ if \ r=0 \\ 0.32 \ if \ r=1 \\ 0.16 \ if \ r=2 \\ 0.10 \ if \ r=3\end{Bmatrix} . \tag{1}$$

The second term takes into account the local brightness based on the gray level values of the low pass version of the image. Since Lewis and Knowles assumed that the eye is less sensitive in the regions with high brightness, they proposed to compute this factor in the following way:

$$L'(r,i,j)=\begin{Bmatrix}1-L(r,i,j), & if\, L(r,i,j)<0.5 \\ L(r,i,j), & otherwise\end{Bmatrix}. \tag{2}$$

where

$$L(r,i,j)=\frac{1}{256}D_3^3(1+\left\lfloor\frac{i}{2^{3-r}}\right\rfloor,1+\left\lfloor\frac{j}{2^{3-r}}\right\rfloor). \tag{3}$$

Finally, the third term

$$\begin{aligned}T(r,i,j)=\sum_{k=1}^{3-r+1}16^{-k}\sum_{s=\{1,2,3\}}\sum_{m=0}^{1}\sum_{n=0}^{1}\left[D_{k+r-1}^{s}\left(m+\left\lfloor\frac{i}{2^{k-1}}\right\rfloor,n+\left\lfloor\frac{j}{2^{k-1}}\right\rfloor\right)\right]^2 \\ \cdot Var\left\{D_N^{LL}\left(\{1,2\}+\left\lfloor\frac{i}{2^{3-r}}\right\rfloor,\{1.2\}+\left\lfloor\frac{j}{2^{3-r}}\right\rfloor\right)\right\}\end{aligned} . \tag{4}$$

gives a measure of texture activity in the neighborhood of the pixel. With Eq.1 toEq.4 can be critical of the visual threshold of wavelet coefficients:

$$jnd_r^s(i,j)=0.5F(r,s)L'(r,i,j)T(r,m,n)^{0.2}. \tag{5}$$

The Relationship between JND and SVD

Since the scheme we proposed in this paper is to embed watermark in the host image singular value matrix, so the JND value can not be directly used as the embedding strength, the amending of singular value [8] proposed by Bo Ruan is a good solution to this problem, the embedding strength in his paper is calculated as follows:

$$\alpha_s=\frac{|\delta_{\sigma 1}|}{S_{w'}(1,1)}=\frac{\min\limits_{0\le x\le N,0\le y\le M}\left\{\frac{JND(r,s,x,y)}{\left|u_{s1}v_{s1}{}^{T}\right|(x,y)}\right\}}{S_{w'}(1,1)}. \tag{6}$$

which $S\in\{LL,LH,HL,HH\}$,r=0 means 3-level DWT to the image, $\delta_{\sigma 1}$ means the first variable of each band, $S_{w'}(1,1)$ represent the first singular value of the scrambled watermark image.

SVD of Digital Image

From linear algebra [9] perspective, a pair of digital image can be regarded as a matrix consist of many nonnegative scalar.Used $A\in R^{m\times n}$ to represent an image matrix, R denote real number field. Without loss of generality, then there exists orthogonal matrix $U=[U_1, U_2,\cdots U_n]\in R^{m\times n}$ and orthogonal matrix $V=[V_1,V_2,\cdots V_n]\in R^{m\times n}$ makes

$$U^T AV = diag(\sigma_1,\sigma_2,\cdots\sigma_n)=S. \tag{7}$$

That $S=U^TAV$, which $p=min\{m， n\}$, $\sigma_1\ge\sigma_2\ge\sigma_p\ge 0$, Since U and V are orthogonal, so

$$A=USV^T=\sum_{i=1}^{N}\sigma_i u_i v_i^{\,T}. \tag{8}$$

where α_i as the singular values of A , u_i , v_i are called singular value corresponding to the left and right singular vector,and satisfies : $AV_i = \sigma_i u_i, AU_i = \alpha_i v_i, (i = 1,2,\cdots p)$ .Therefore the U and V column are respectively the eigenvector of AA^T and $A^T A$, then S is the singular value decomposition (SVD) type of A.

Watermarking Scheme

Watermark Signal Generation. In order to improve the security, the original watermark image is operated by Arnold transform, the Arnold transform is shown in Eq. 9.

$$\begin{pmatrix} m' \\ n' \end{pmatrix} = \begin{pmatrix} m \\ n \end{pmatrix} \times \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} (\bmod N). \tag{9}$$

Embedding Process. In order to satisfy both transparency and robustness, the watermark is repeatedly embedded in the LL band and LH band of three channels. The embedding process of *R* channel is as follows (*G* and *B* channels similar):

(1) The SVD decomposition of the watermark image, *S,U,V* respectively means singular values of watermark images, singular value matrix of the left and right singular value matrices;

(2) Extract the original color image of the *R* component; render 3-level DWT to the *R* channel and extract the wavelet coefficients of the *LL3*and the *LH3*, then obtain the singular value of them. $S_{HL}, S_{LL}, U_{HL}, U_{LL}, V_{HL}, V_{LH}$ denote the singular value, image left singular value matrix and right singular value matrix;

(3) Using Eq. 5 and Eq. 6 calculation variable of *LL3* and *LH3* coefficients, separately embed watermark according to the Eq.10and Eq.11 ;

$$R_{HL} = U_{HL}(S_{HL} + \alpha_{HL} S)V_{HL}. \tag{10}$$

$$R_{LL} = U_{LL}(S_{LH} + \alpha_{LL} S)V_{LL}. \tag{11}$$

(4) Render 3-level IDWT to the *R* channel having embedded watermark, and obtain the new *R* channel. Using the above (1) to (4) steps are available to the new *G*, *B* component, and then the three components will be combined into a new *RGB* color images.

Extracting Process. Watermark extraction is approximately the inverse process of watermark embedding, here are given only the extracting process of the *R* channel (*G* and *B* cheannels similar):

(1) Render 3-level DWT respectively to the original *R* channel and the new *R* channel, extract the *LL* and *LH* of the watermarked image, and obtain singular value matrix S'_{HL}, S'_{LL} ;

(2) Obtain the watermark's singular value matrix by the singular value matrix of *LL* and *HL* of the original image and watermarked image using Eq. 12 and Eq. 13;

$$S'_1 = \frac{S'_{HL} - S_{HL}}{\alpha_{HL}}. \tag{12}$$

$$S'_2 = \frac{S'_{LL} - S_{LL}}{\alpha_{LL}}. \tag{13}$$

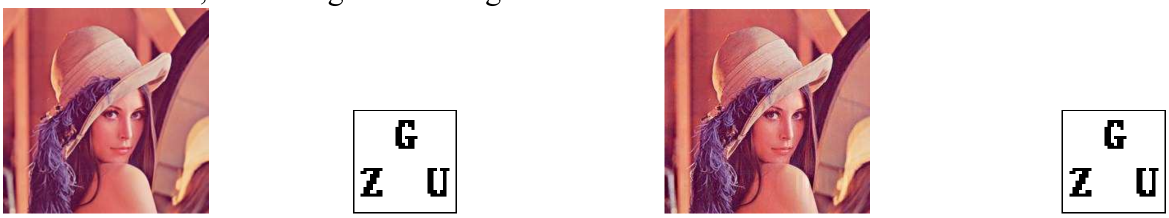
(3) Combine S_1',$S_2'$and original *U,V*, get watermark by SVD inverse transformation;

(4) Render the reverse Arnold process to watermark , in order to improve the robustness the *NC* (Normalized Correlation) value is calculated respectively between the two watermark image extracted and the original watermark image, and that the *NC* value is the bigger one.

Using the same method, watermark image Water2, Water3 can be extracted from *G* and *B* channels respectively, the *NC* (Normalized Correlation) value is calculated and that the *NC* value is maximum of all is the final one.

Experiment Results

The experimental platforms are MatlabR2010a, the host image size selected 256 × 256 × 24 standard color image 'Lena', (see Figure 1 (a)), and the original watermark is a binary image of size 32×32 shown in (see Figure 1 (b)), from Figure 1 (c) can be seen that the watermark image is consistent with original image , that is, the watermarked image can still maintain good visual quality, in order to eliminate subjective factors, we use the peak signal to noise ratio (PSNR) to evaluate the image, measured from the experimental simulation of the image watermark PSNR = 64.1985db, therefore, the proposed algorithm can guarantee the embedded watermark is inaudible. From Figure 1 (d) can be seen, the watermark image at the end of the case of attack, the watermark can be extracted intact, indicating that this algorithm can extract the watermark to ensure consistency.



(a) Original Lena (b) Original watermark (c) Watermarked Lena (d) Extracted watermark

Figure .1 Host image and watermarked image.

Table 2. JPEG compression simulation

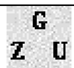
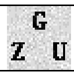
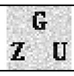
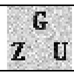
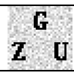
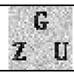
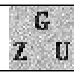
Quality	90	80	70	60	50	40	30
NC	0.99904	0.99864	0.99734	0.9947	0.99432	0.9929	0.9919
PSNR	58.9395	58.6395	58.2202	55.823	54.5238	53.8922	53.1194
Extract watermark							

Table 3.Nosie attacking simulation

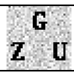
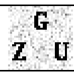
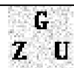
Attack	Gaussian noise （0.005）	Gaussian noise （0.01）	Gaussian noise （0.02）	Salt and pepper noise (0.02)	Salt and pepper noise（0.05）	Salt and pepper noise（0.08）
NC	0.9951	0.99141	0.98151	0.99407	0.98874	0.97234
PSNR	55.3032	52.016	44.1038	46.2012	40.8215	35.7287
Extract watermark						

Table 4. Filtering attacking simulation

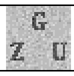
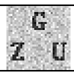
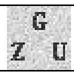
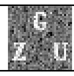
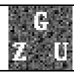
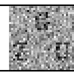
Attack	Gaussian low-pass	Median filtering(3×3)	Median filtering(4×4)	Median filtering(5×5)	Median filtering(6×6)	Median filtering(7×7)
NC	0.93373	0.99453	0.96281	0.92846	0.7974	0.64854
PSNR	36.1019	53.5436	50.1263	47.8976	44.0276	40.9222
Extract watermark						

Table 5.Cut and rotate attacking simulation

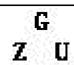
Attack	Upper left corner cut 1/16	Cut the upper left corner and upper right corner, 1/16	Four corners were cut 1/16	Center cut 1/4	Centre set to cut 1 / 4, the upper right corner cut 1 /16	Rotation 10 degrees
NC	1	1	1	1	1	0.9993
PSNR	30.2941	29.2904	27.2827	27.249	27.2435	26.7436
Extract watermark						

Table 1- 5demonstrates the effects of the extracted watermark from watermarked Lena image which has subjected to various attacks. It can be seen that the propose scheme has a higher robustness against various attacks such as JPEG compression, cropping, median filtering, Gaussian low-pass filtering, adding noise, Gaussian blur, sharpening, etc.

Table 6. Comparison of PSNR in two methods.

	Schem[6]	Proposed scheme
PSNR	41.0264	64.1985

Table 7. Results compared with Schem[6]

Attack / NC	Crop 1/16	Crop 5/16	Gaussian low-pass	Rotation 10 degrees	0.02 Gaussian noise	0.05 Salt and peppe	Median filtering 3×3	JPEG 90%	JPEG 70%	JPEG 60%	JPEG 50%
Proposed scheme	1	1	0.93373	0.9993	0.98151	0.98874	0.99453	0.99904	0.99734	0.9947	0.99432
Scheme (6)	0.9021	—	0.9785	0.9785	—	0.9864	—	—	0.9950	0.9894	0.9887

We also compared the results from the propose scheme with the results from the scheme reported in [6], which based on SVD. The host image used in compared experiments is Lena. Table 1 shows the comparison of PSNR, is easy to see from Table 6 , this algorithm has better watermark transparency. Table 7 shows that the proposed scheme has a much better invisibility than the proposed scheme reported in [6], and it is also found that improved robustness against various attacks including filtering, cropping attacks, etc.

Conclusions

This paper presents a DWT-SVD domain adaptive digital image watermarking algorithm. The algorithm first render 3-level IDWT to the image then get the R, G, B three channels and each sub-band Arnold scrambled with watermark image, using the human visual system (HSV) adaptively adjust the watermark embedding strength, the watermark is added to the original image singular value of the sub-band of the singular value. Of course, there is a problem about blind extracting, we should strengthen research on it, so that algorithm is more practical.

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