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A 3D-DCT-Based Information Hiding Algorithm for Color Images[1)]

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Abstract An information hiding algorithm for color images is proposed. This algorithm not only can hide data as many as 2048 bytes, but also can implement blind detection of the hidden information without resorting to the original image or any other additional information. The algorithm can trade off the conflict of invisibility and robustness of the invisible watermark by adopting 3D-DCT and the embedding method in this paper. The proposed algorithm adopts error-correcting coding and data interleaving techniques to improve the performance of resisting diverse attacks. The experimental results show that the hidden watermark is robust, even when the bit error rate before correction can be $3\times10^{-1}\sim3\times10^{-2}$ under many attacks in StirMark.

Key words Blind detection, information hiding, 3D-DCT, robustness, color image watermarking

1 Introduction

Among the researches on information hiding, the blind extraction algorithm for hidden information bits is one of the research areas with great value in applications but more difficulties. The main problems faced by the information hiding algorithms include: how much information can be conveyed, what conditions are needed by the detection procedure and how robust the information is after encountering attacks.

Most of the earlier algorithms embed random sequences as watermark and the robustness of resisting attacks is good[1~3]. But as the random sequence watermark can convey only 1 bit and its readability is poor, this kind of algorithms is limited in applications. So, algorithms with meaningful text or image are proposed one after another[4,5]. However, the existing algorithms have shortcomings as follows: 1) The amount of hidden information is small. For example, some of them can embed only a few dozens of valid bytes; 2) The robustness is not so good, for the $4\times10^{-1}\sim10^{-2}$ error bit rate brought by various attacks can cause most of the watermarks to fail; 3) The detection procedure needs the original image. Moreover, most of the researches are focused on gray-scale images, while the color image watermarking algorithm has not been adequately researched.

In this paper, a 3D-DCT(three dimensional discrete cosine transform) based information hiding algorithm for color images with blind detection is proposed. The features of the proposed algorithm are as follows:

1) Embedded watermark as meaningful text or image;

2) Huge amount of the embedded watermark, up to 2048 bytes data in a 512×512 RGB color image;

3) Blind detection without resorting to the original image or any other side information;

4) FEC (Forward Error Correcting) coding technique and permutation technique to improve robustness of the hidden information.

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This paper proceeds as follows. Section 2 describes and discusses the proposed embedding algorithm. In Section 3, the detection procedure is provided. Section 4 shows the experimental results and discussion. Conclusions are given in Section 5.

2 The embedding algorithm

The block diagram of the information embedding algorithm is shown in Fig. 1.

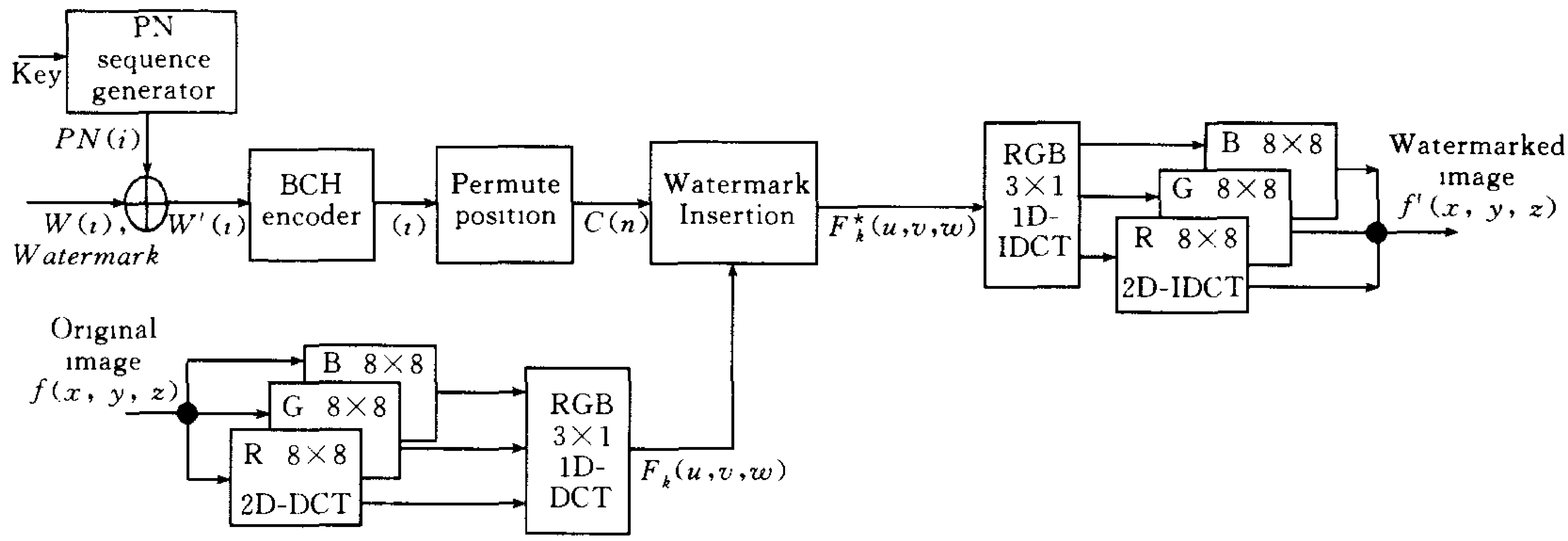


Fig. 1 The block diagram of the information embedding algorithm

The existing color image watermarking algorithms[6,7] usually use the Y component or other single color component to embed information. And the algorithm in [8] simply takes advantage of the RGB cross-correlation. The proposed algorithm in this paper applies 3D-DCT to the three RGB color components to take full advantage of the capacity of the host image, thus resulting in better robustness and invisibility of the hidden information. In this paper, the data hiding is regarded as a digital communication system. The proposed data hiding algorithm introduces some digital communication techniques, such as encryption, BCH error correcting coding, and permutation to improve robostness to attacks.

2.1 3D-DCT of color image

We denote RGB color image as $f(x,y,z)$ ($z=0,1,2$, denoting R,G,B color components, respectively). $f(x,y,z)$ is first segmented into non-overlapped $8\times8\times3$ 3D blocks $f_k(x',y',z)$ ($k=0,1,2,\cdots,K-1$; $x',\ y'=0,1,\cdots,7$; $z=0,1,2$). Then block-wise 3D-DCT is applied to $f_k(x',y',z)$ and frequency domain coefficients $F_k(u,v,w)$ ($k=0,1,2,\cdots,K-1$; $u,v=0,1,\cdots,7$; $w=0,1,2$) are obtained.

According to [2,9], the DCT coefficients, which are chosen for embedding the information, need to meet the following requirements:

1) The coefficients can be well preserved after commonly used signal processing and noise adding. That is, these coefficients should not be altered too much by signal processing and noise. This requirement is to guarantee better robustness of the hidden watermark. It is clearly that the smaller the coefficients with watermark components are changed, the better the watermark can be preserved.

2) The coefficients must possess much perceptual capacity so that the embedded watermark will not bring obvious change to the host image quality. Embedding watermark in an image can be viewed as imposing a weak signal on a strong background. According to Weber's Law and the contrast characteristics of HVS, the more perceptual capacity the more the coefficients can be changed under the constraint of invisibility, and also the stronger watermark signal can be embedded.

People usually think that HVS will be more sensitive to the change in the low frequency component. So the early watermarking algorithms embedded watermarks by changing the middle or high frequency components. However, these algorithms have overlooked the fact that in general, the amplitudes of low frequency components are much larger than those of the middle/high frequency components (several dozens of times, even several hundreds of times. The higher the frequency, the smaller the average amplitude is.) So the low frequency components have more perceptual capacity. Under the constraint of invisibility, although the proportion of change to the low frequency component is smaller than that to the middle/high frequency, the absolute amplitude of change to the low frequency component is much larger. Cox *et al.*[2] proposed that the watermark should be inserted into the low frequency components to improve the robustness. Choosing low frequency AC coefficients to embed watermark has been widely adopted. In [8] this embedding strategy is extended, and it is pointed out that the DC component is more suitable to embed watermark in order to obtain better robustness under the constraint of invisibility.

The above analysis shows that the amplitude of the coefficient in the transform domain affects the robustness of watermark directly. So we apply statistic analysis to the 3D-DCT coefficients and Y component 2D-DCT coefficients of many RGB color images. The results are shown in Fig. 2, where the x-axis (log coordinate) is the position of the 64 zigzag scanned coefficients of 8×8 block, while the y-axis the absolute value of the magnitude of DCT coefficients. Curves (1), (2) and (3) show the statistical distribution of DC ($F_k(u,v,0)$ $k=0,1,2,\cdots,K-1$; $u,v=0,1,\cdots,7$), AC_1($F_k(u,v,1)k=0,1,2,\cdots,K-1$; $u,v=0,1,\cdots,7$) and AC_2($F_k(u,v,2)k=0,1,2,\cdots,K-1$; $u,v=0,1,\cdots,7$)coefficients of 3D-DCT for a few commonly used images. Curves (4), (5) and (6) are the statistical distribution of the 2D-DCT coefficients for R, G, and B components, respectively. Curve (7) is the statistical distribution of 2D-DCT coefficients for the Y component (luminance) after performing a conversion from RGB to YUV.

Fig. 2 shows that for RGB color images, 2D-DCT can remove the spatial correlation of each color component and concentrate energy of each component into a few DCT coefficients. But the correlation among the color components still exists. 3D-DCT can further remove the correlation among the color components and concentrate the energy distributed in each color component into a few 3D-DCT coefficients.

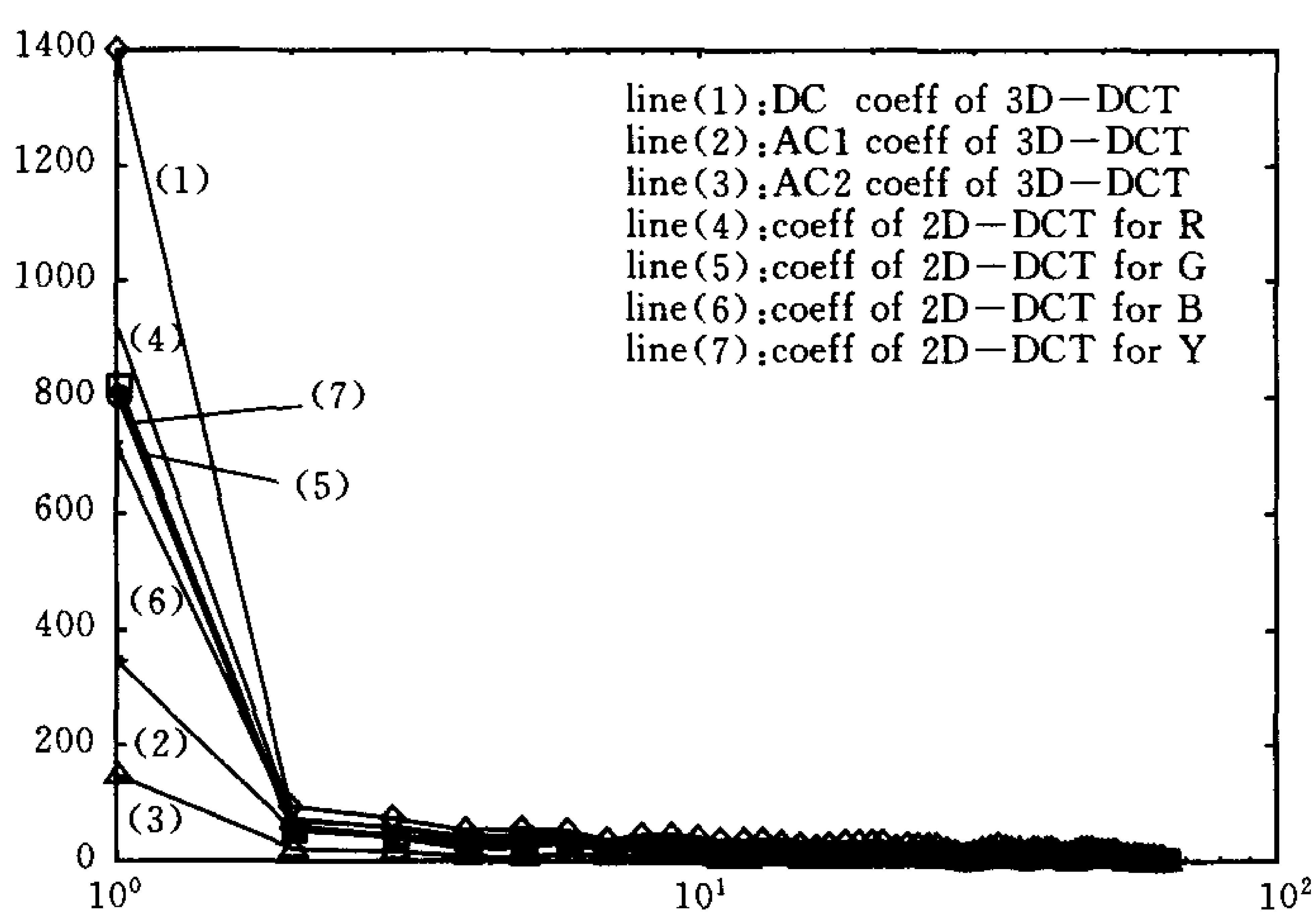


Fig. 2 Statistical distributions of 8×8 2D-DCT and $8\times 8\times 3$ 3D-DCT coefficients

The above theoretical analysis and our experimental results prove that 3D-DCT coefficients can meet the requirements in[2,8] better than 2D-DCT coefficients of each color component, and also better than 2D-DCT coefficients of Y component after performing a conversion from RGB to YUV. 3D-DCT can trade-off the conflict of transparency and robustness of the hidden information well. It's reasonable to choose 3D-DCT in color image information hiding algorithm.

2.2 Encryption

We encrypt the hidden information $W(i)(i=0,1,2,\cdots,I-1)$ with a pseudo random binary sequence $PN(i)$ generated by a secret key Key, $W^*(i)=W(i)\oplus PN(i)(i=0,1,2,\cdots,I-1)$, where I denotes the byte length of watermark. From the point of view of information hiding and information security, it's necessary to make the information secret and random. This processing can incorporate information hiding with encryption technique, and provide a basis for authentication of the hidden information.

2.3 BCH ECC coding

We apply (n,k) BCH ECC to the encrypted information $W^*(i)$:

$$B(i) = G * W^*(i) \quad (i = 0,1,2,\cdots,I-1)$$

where G denotes the generator matrix of (n, k) BCH ECC code. In our experiments, we choose BCH code based on the following reasons:

1) There are many choices of (n,k) combination for the same capability in error correcting;

2) The capability in error correcting is powerful when the block length is moderate;

3) Ample algebraic encoding/decoding algorithms exist.

For BCH code, in general, the less the k/n, the more powerful the error correcting performance is. Besides, it's convenient to represent the information in byte. So we choose $k=8$. The determination of code length n is a trade-off between the error correcting performance and a certain capacity constraint of the host image. In our experiments, we choose (127,8) BCH code . The generator polynomial in octal is:

$$g(x) = \{7047264052 \quad 7510306514 \quad 7622427156 \quad 7733130217\}.$$

2.4 Permutation

The errors caused by various attacks can be random or burst, and the burst error caused by cropping, row and column removal is critical. Because the performance of correcting burst error of BCH code is worse, we adopt permutation technique to improve the robustness to cropping. The experimental results show that permutation can well resist burst error caused by cropping, row and column removal. The permutation steps are as follows.

• Permute the BCH coded information bytes, the byte number is $i(i=1,2,3,\cdots,I)$.

When I is even,

$$\begin{cases} B'(2k-1) = B(k), & k = 1,2,3,\cdots,[I-1]/2; \\ B'(2k) = B(k+[I-1]/2), & k = 1,2,3,\cdots,[I+1]/2. \end{cases}$$

When I is odd,

$$\begin{cases} B'(2k-1) = B(k), & k = 1,2,3,\cdots,[I-1]/2; \\ B'(2k) = B(k+[I-1]/2, & k = 1,2,3,\cdots,[I+1]/2. \end{cases}$$

• Permute bits in each byte, the bit number is $j(j=1,2,3,\cdots,8)$

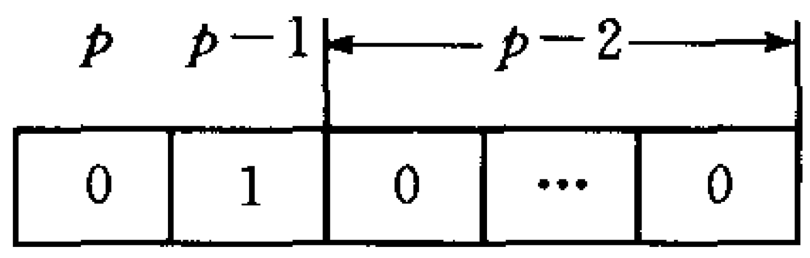
$$\begin{cases} C^*_{2l}(i) = B'_l(i), \ l = 1,2,3,4; \\ C^*_{2l+1}(i) = B'_{l+4}(i), \ l = 1,2,3,4. \end{cases}$$

• Output the first bit $C^*_1(i)$ from each byte in the order of $i(i=1,2,3,\cdots,I)$, then the second bit, and so on, until the eighth bit is output to the bit stream $S(i,j)=C^*_j(i)$ $(i=1,2,3,\cdots,I;\ j=1,2,3,\cdots,8)$, whose length is $8*I$ bits.

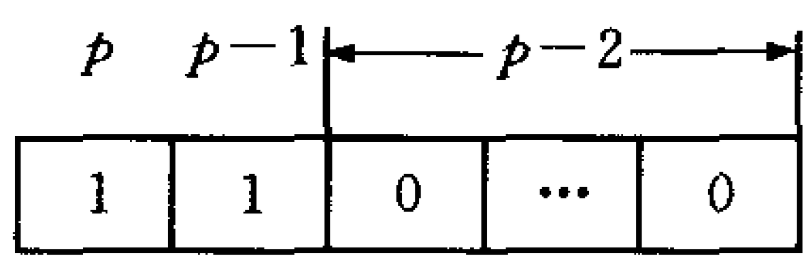
2.5 Data embedding

According to the embedding strategy in [2,8] and the analysis to the DCT coefficients, we choose 4 components DC, AC, AC2, AC3 of $8\times8\times3$ 3D-DCT coefficients $F_k(u,v,w)(u,v=1,2,\cdots,8;w=0,1,2)$ for embedding data. The embedding method is as follows.

When $S(i,j)=$"0", the p least significant bits of the selected coefficient $F_k(u,v,w)$ are replaced by a p bits binary natural code, whose serial number is 2^{p-2}. That is, the information bit "0" is represented by a p bits binary codeword:



When $S(i,j)=$"1", the p least significant bits of the selectedcoefficient $F_k(u,v,w)$ are replaced by a p bits binary natural code, whose serial number is $2^{P-1}+2^{P-2}$. That is, the information bit "1" is represented by a p bits binary codeword:



where $k=1,2,\cdots,K-1$; $i=1,2,\cdots,I$; $j=1,2,\cdots,8$; $u,v=1,2;w=2$.

The determination of P is related to the texture complexity of the host image. The larger the P, the stronger the strength of the embedded signal is, and the more visible the embedded information is. P can be $4\sim7$. In order to maximize the capability of resisting additive noise, we adopt P bits natural code whose serial number is 2^{p-2} and $2^{P-1}+2^{P-2}$ to represent information bit "0" and "1", respectively. From the point of view of quantization, for a p-bit binary natural code, there are 2^P quantization levels. If we embed information bits with the above method, and set the judging threshold as a p-bit natural code whose serial number is 2^{P-1}, the capability of the hidden information in resisting additive noise is the best. When the corruption caused by the additive noise is in the range of $-(2^{P-2})\sim+(2^{P-2}-1)$ quatization levels, the hidden information bit can be recovered correctly.

2.6 3D-IDCT

Lastly, we apply block-wise 3D-IDCT to obtain the watermarked RGB color image $f^*(x,y,z)$.

3 Watermark detection

Watermark detection is the inverse procedure of the embedding algorithm. The main steps in detection are as follows.

1) We denote $f^*(x,y,z)$ as the possibly corrupted watermarked image. $f^*(x,y,z)$is first segmented into non-overlapped $8\times8\times3$ 3D blocks $f_k^*(x',y',z)(k=0,1,2,\cdots,K-1;x',y'=0,1,\cdots,7;z=0,1,2)$. Then block-wise 3D-DCT is applied to $f_k^*(x',y',z)$ and the frequency domain coefficients $F_k^*(u,v,w)(k=0,1,2,\cdots,K-1;u,v=0,1,\cdots,7;w=0,1,2)$ are obtained.

2) Among each $8\times8\times3$ 3D-DCT coefficients block $F_k^*(u,v,w)(u,v=1,2,\cdots,8;w=0,1,2)$, pick up the pth least significant binary bit of the integer part of DC, AC1, AC2, and AC3, respectively, as the information bit.

3) De-permutation. The algorithm is the same as the permutation in Section 2. 4.

4) BCH decoding. Firstly segment the extracted information bits into a serial sub-sequence of 127 bits; then for each sub-sequence, search in BCH signal set for a codeword which has the shortest distance with the sub-sequence; regard the codeword as the embedded byte.

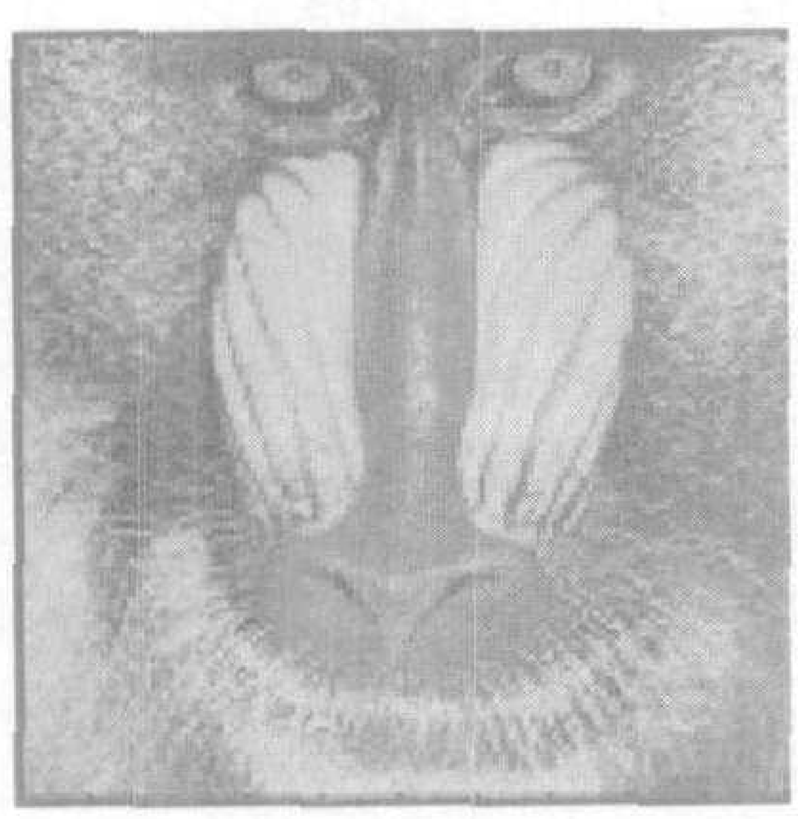
5) Decryption. The algorithm is the same as encryption in Section 2. 2.

4 Experimental results

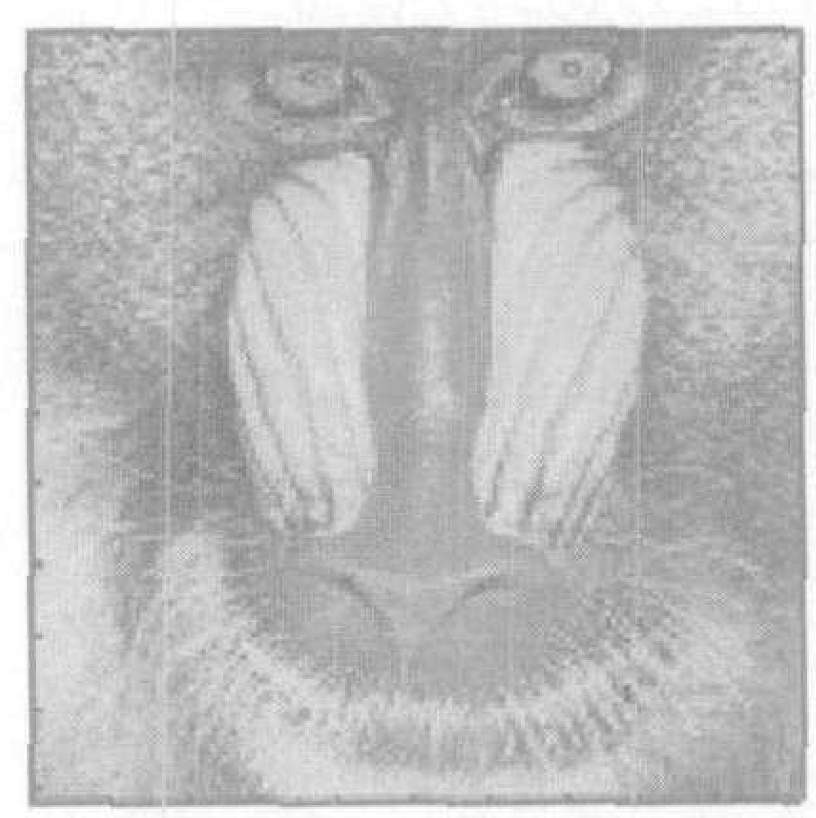
In our experiments, two RGB color images "Lena" and "Baboon" with different texture complexity are used to embed information. In a 512 × 512 color image, we embed meaningful characters shown in Fig. 4(a) (129 bytes). Fig. 3 demonstrates the invisibility. Fig. 3(a) and Fig. 3(c) are the original images of "Lena" and "Baboon", respectively. Fig. 3(b) and Fig. 3(d) are the watermarked images of "Lena" and "Baboon", respectively. We can see that even the watermarked image is put together with the original image, no obvious difference can be percepted. We also test our algorithm by StirMark 3.1. The results are shown in Fig. 4 and Table 1.

(a) Original image

(b) Watermarked image($PSNR$=40.61dB)

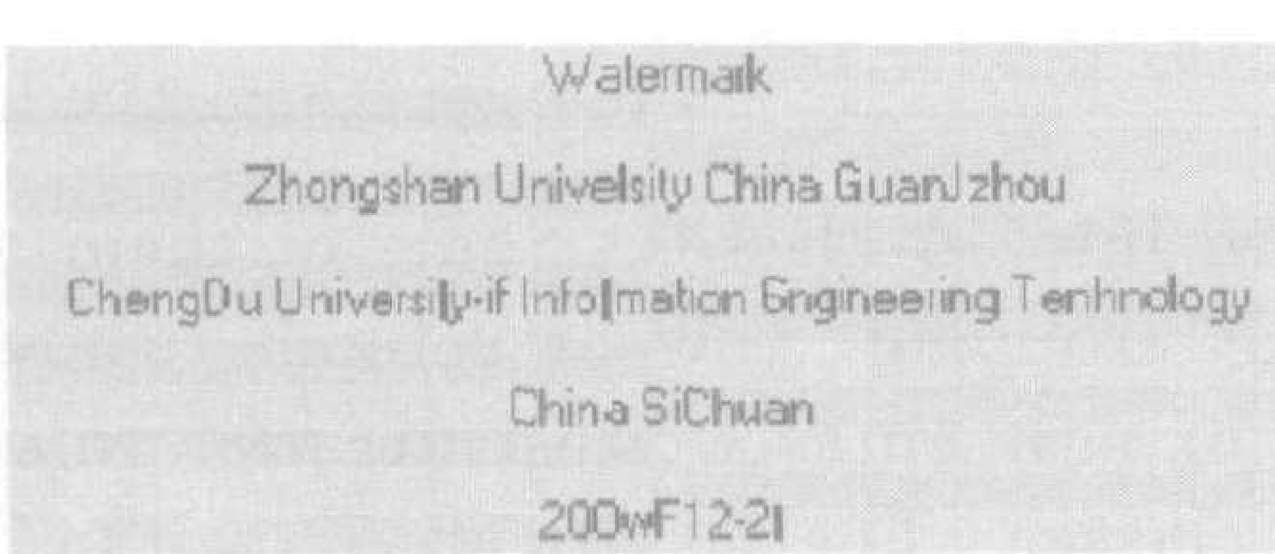


(c) Original image

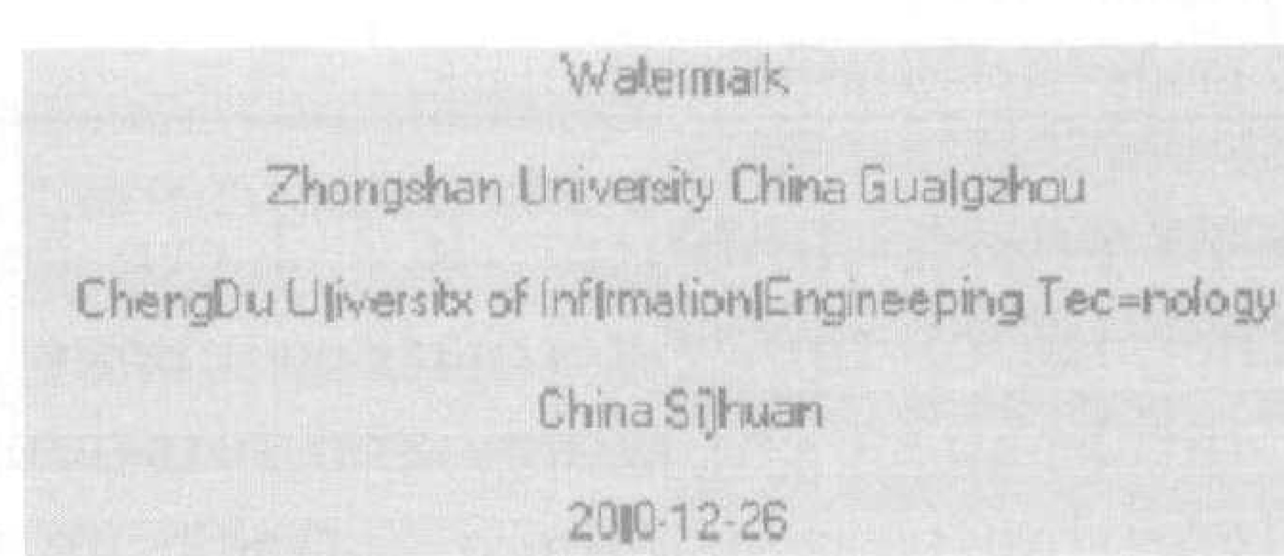


(d) Watermarked image($PSNR$=40.72dB)

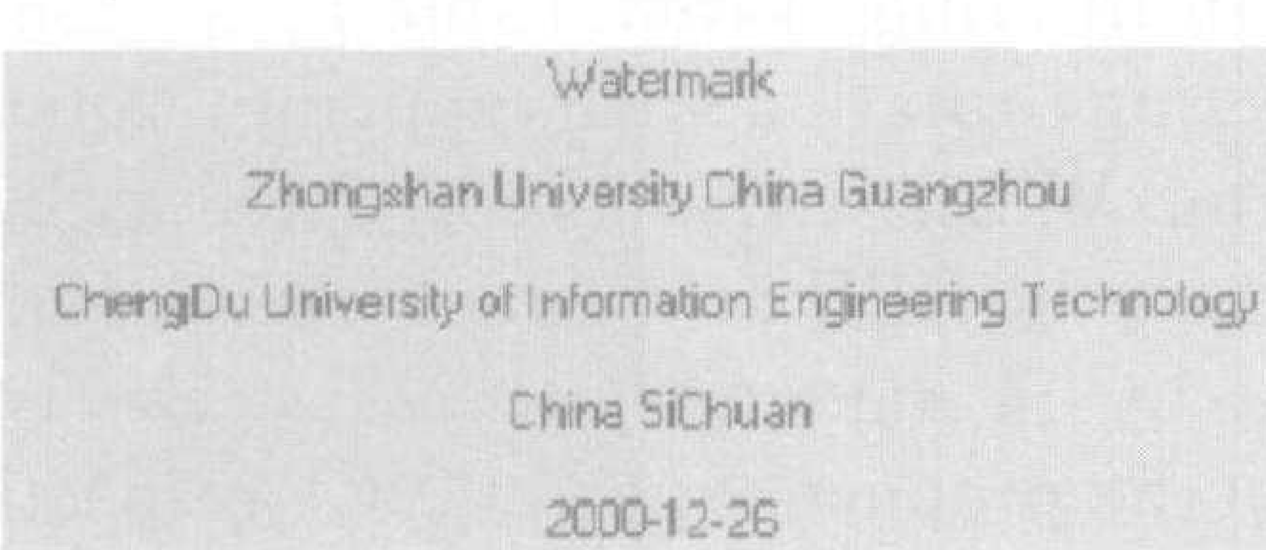
Fig. 3 The demonstration of invisibility



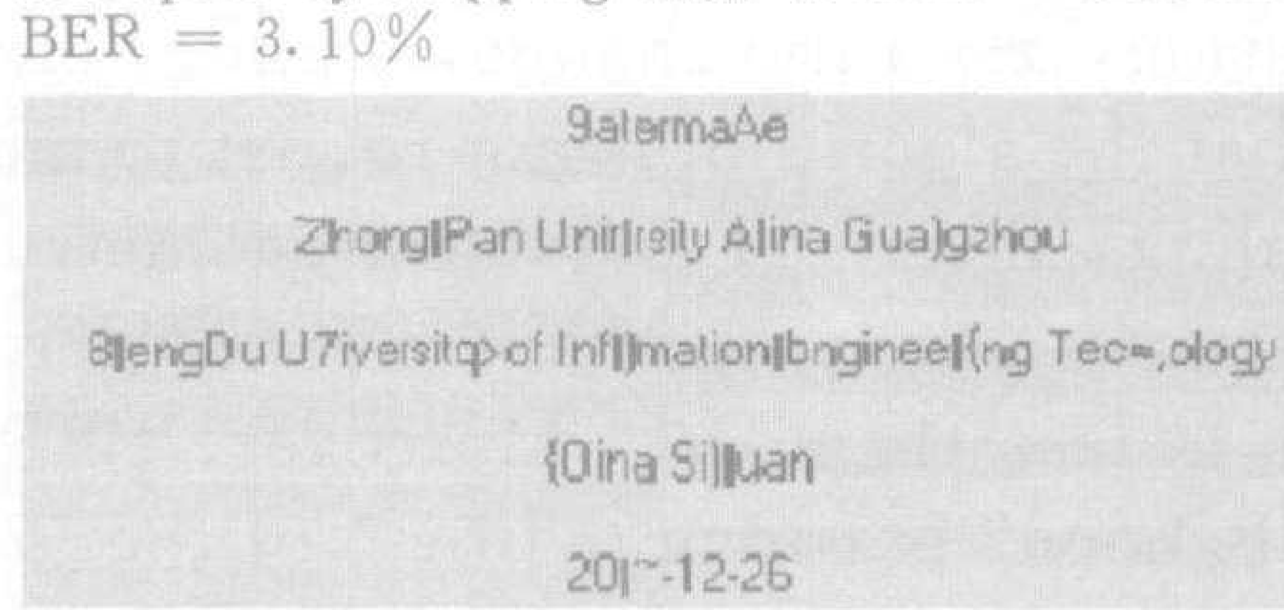
(a) original watermark



(b) extracted watermark when watermarked image "Lena" corrupted by cropping 10% (PSNR = 34.21dB), BER = 3.10%



(c) extracted watermark when watermarked image "Baboon" corrupted by removing 5 rows and 1 column (PSNR = 25.26 dB), BER = 4.65%



(d) extracted watermark when watermarked image "Lena" corrupted by cropping 25% (PSNR=33.89dB, BER=12.02%

Fig. 4 The demonstration of robustness

Table 1 Robustness to Stirmark 3.1

Attacks	Lena		Baboon	
	PSNR(dB)	*BER*(%)	*PSNR*(dB)	*BER*(%)
Remove 1 row and 1 column	33.22	0	27.74	0
Remove 1 row and 5 columns	31.86	0	23.70	0.97
Remove 5 rows and 1 column	30.65	0	25.26	4.65
Remove 5 rows and 17 columns	29.83	0	22.81	16.67
Remove 17 rows and 5 columns	29.86	0	22.68	19.67
Median filtering (2×2)	27.94	15.21	22.41	48.64
Median filtering (3×3)	29.81	6.59	24.36	44.67
Cropping_1 (506×506 left in 512×512)	33.81	0	28.30	0.97
Cropping_2(501×501 left in 512×512)	33.86	0	28.37	1.45
Cropping_5(486×486 left in 512×512)	33.97	0	28.55	3.10
Cropping_10(460×460 left in 512×512)	34.21	3.10	29.11	7.56
Cropping_25(384×384 left in 512×512)	34.89	12.02	30.62	12.40
JPEG Qut=40	31.18	0.87	25.09	26.84
JPEG Qut=50	31.60	0	25.51	17.05
JPEG Qut=60	32.46	0	26.46	5.72
Change aspect ratio_x_0.80_y_1.00	31.36	0.19	24.50	32.75
Change aspect ratio_x_1.00_y_0.80	30.53	0.29	25.14	31.78
Change aspect ratio_x_1.00_y_1.10	29.15	0.78	24.78	32.85
Change aspect ratio_x_1.10_y_1.00	30.01	0.68	24.26	35.37
Change aspect ratio_x_1.00_y_1.20	30.57	0	25.98	21.51
Change aspect ratio_x_1.20_y_1.00	31.29	0	25.44	30.81
Rotation_0.25 with cropping_510×510	26.54	30.33	19.18	41.96
Scale_0.50	29.08	0.39	22.42	18.80
Scale_0.75	30.66	0.39	24.23	21.32
Scale_0.90	30.99	1.36	24.77	35.76
Scale_1.10	33.75	0	27.88	0
Scale_1.50	33.33	1.16	27.61	17.25
Shearing_x_0.00_y_1.00	25.08	27.23	18.40	45.35
Linear transformation $(u,v)=[1.007,\ 0.010;\ 0.010,\ 1.012](x,y)$	20.39	47.00	17.57	51.55
Gaussian_filtering (3×3) [1 2 1;2 4 2;1 2 1]	31.37	0	24.55	17.25
Sharpening (3×3) [0−1 0;−1 5−1;0−1 0]	21.12	50.48	15.38	51.84
StirMark random_bend	18.00	49.61	15.19	53.39
Frequency mode Laplacian removal attack	30.80	50.29	26.94	46.32

The 88 attacks in Stirmark 3.1 can be classified into 14 classes. Some of them will change the size of the watermarked image , such as cropping, row or column removal, scaling, ratio-aspect changing, and rotation. In our experiments, we test the performance of our algorithm to resist the 57 attacks in these 14 classes. The results are shown in Table 1. Form Table 1, we can see that our algorithm is robust to jitter, cropping, JPEG compression, x-y ratio change, scaling, and Gaussian-filtering. From Table 1, we can also see that the algorithm is not robust to median filtering, rotation with cropping, rotation with scaling, shearing, and linear geometry transform. When "Lena" is corrupted by 22 of the 57 attacks (the proportion is 38.6%) respectively , the BER of the recovered information bits is less than 1%. Moreover, BER brought by 14 among these 22 attacks is 0. When "Baboon" is corrupted by 4 of the 57 attacks (the proportion is 7.02%) respectively, the BER of the recovered information bits is less than 1%. Moreover, BER brought by 1 among these 4 attacks is 0. Fig. 4 shows that, for meaningful characters, when BER is less than 5%, the watermark can be identified.

5 Conclusions

In this paper, we discuss and implement a blind detection algorithm for meaningful information bits in color image. The merits of the algorithm are as follows.

1) We propose to apply 3D-DCT to the color image to embed information in color images. The theoretical analysis and experiments results demonstrate that the idea is reasonable.

2) Implement blind detection.

3) Adopting ECC and interleaving in informatin hidding. The experiments results show that these methods can improve the performance of resisting various attacks effectively.

The algorithm not only can embed 2048 bytes data in a 512×512 RGB color image, but also can extract the watermark without resorting to the original image or any side information. Meanwhile, the robustness of resisting various attacks is good. Our algorithm outperforms the algorithm in [4] because we need no side information in the extraction procedure, outperforms the algorithm in [6] because we can embed much more data. But because the algorithm is based on DCT, it can not resist geometry attacks.

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一种基于3D-DCT的彩色图像信息隐藏算法

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摘 要 提出了一种基于3D-DCT的彩色图像信息隐藏盲检测算法.本算法不但可以在512×512的RGB彩色图像中嵌入多达2048字节的数据,而且实现了完全盲检测,即在信息检测时,该算法不需要原始图像和任何附加信息.同时,采用3D-DCT和算法中的信息嵌入方式,能充分地利用信息载体的容量,很好地平衡隐藏信息的不可见性和稳健性之间的矛盾.算法采用了纠错编码技术和数据扰乱技术,以提高算法抵抗各类攻击的性能.实验证明,该算法所隐藏的信息在StirMark的攻击下,对高达$3\times10^{-1}\sim10^{-2}$的误比特率,仍具有很好的稳健性.

关键词 盲检测,信息隐藏,3D-DCT,稳健性,彩色图像水印

中图分类号 TP391

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Important Dates

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