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A Covert Communication-Oriented Carrier Pre-Processing Scheme based on CARDBAL2 and Color Transfer Theory

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Abstract: In view of feature matching between carrier and secret images, an information hiding scheme based on CARDBAL2 and color transfer theory is proposed as CDB-CTT to improve the hiding performance. Quantifying the energy and structure features into adaptable parameters, the proposed scheme consists of two key parts: (1) the energy of the carrier image will be mainly distributed in the four components with different robustness such as LL_2, LH_2, HL_2 and HH_2 in the sub-image after first-order CARDBAL2; (2) the color transfer theory is used to analyse the structure feature into some modifiable bits and to realize the embedding operation. Based on the above two points, the modification after embedding can be minimized. Experimental results indicate that our scheme can increase imperceptibility by 24.47% averagely and robustness at least 20.14%, and obtain excellent sensitivity of image processing.

Keywords: information hiding; CARDBAL2; color transfer theory; $l\alpha\beta$ color space; carrier pre-treatment

1 Introduction

Information hiding is an important way to secure the confidential communication. Improvement of the performance is always a research focus in information hiding scheme based on digital image. It has been believed that the most important purpose for the cover image pre-treatment method is to improve the performance of hiding [1]. Currently, the space domain- and frequency domain-based are the main methods of the cover image pre-treatment for information hiding [2]. LSB is the basic algorithm of space domain methods, but the schemes based on LSB almost have drawbacks under embedding great amount of information [3]. Methods in frequency domain, such as DCT and DWT, have robustness against certain attacks, but are costly and of lowrobustness against rotating attacks [4]. Using spatial- or transform-based pre-treatment method rather than analysing the energy and structure of carrier, the existing information hiding approaches similar with the above methods can achieve neither a good feature matching between the carrier and the secret image nor the minimum distortion to the initial data or coefficient [5].

New technologies about image processing emerged to enrich the pre-processing methods of information hiding carrier. At the same time, more and more researchers want to combine methods of different operand to improve the performance of information hiding. In our previous research, we have studied about several energy and structure analyse methods. By energy analyse, we generally obtain the energy differential regions to embed the data with different robustness, and this procedure can improve the robustness and imperceptibility directly, even other performances. By structure analyse, we can obtain the color and shape parameter of the carriers which can be taken as the modifiable parameters for the embedding. After the pre-treatment based on feature analyse, the embedding procedure can modify the original information of carrier as less as possible. In this paper, we use CARDBAL2 multi-wavelet transform and $l\alpha\beta$ color space theory as the analyse methods. CARDBAL2 multi-wavelet transform, which can satisfy compact support and symmetry of the image processing, was proposed to be a new frequency domain method recently [6]. And in space domain, a color transfer theory was proposed to transfer color from one image to another in

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(a) Lena Normal (b) Lena CARDBAL2 first-order (c) Hiding Region

Fig. 1: First-order CARDBAL2 multi-wavelet transform.

Table 1: Embedding rule.

Modified Bit	Embedding information			
	00	01	10	11
α_C	√	√	α_C'	α_C'
β_C	√	β_C'	√	β_C'

the $l\alpha\beta$ color space [7], which can analysis a digital image carrier in color space. Combining CARDBAL2 multi-wavelet transform technology and color transfer theory, we propose an information hiding scheme. These two methods can analyse the energy and structure characteristics of the carriers into some operable parameters, and then embed the secret information without going against the properties of the carriers. Firstly, the digital image carrier will be processed by first-order CARDBAL2 multi-wavelet transformation. And then four first-order sub-images (LL_2, LH_2, HL_2 and HH_2) can be obtained as the confidential information covert. After that, the four sub-images are analysed as a binary coding sequence by optimization algorithms and coding methods. Information to be hidden will be scrambled with chaotic map [8], and the optimal scrambled parameters can be searched by genetic algorithm [9] in order to improve the consistency between pre-hiding information and the best embedded code; Finally, hiding information can be embedded with RAID4 according to embedding rule based on color transfer theory and the optimal scrambled order. Simulation experiment results illustrate that CDB-CTT is better than traditional algorithms in invisibility and robustness against image attacks such as JPEG2000, cutting, rotation, filtering and noise. Moreover, the CDB-CTT has excellent sensitivity to image attacks.

2 The Proposed Method

2.1 The Embedding Process

We propose CDB-CTT as a cover image pre-treatment method to improve the performance of information hiding. CDB-CTT information hiding scheme has seven steps. The general process is shown in Fig.1:

Step1. The cover image is transformed with first-order CARDBAL2 multi-wavelet, and then the four sub-images are decomposed with $l\alpha\beta$ color space theory. α and β components of sub-images are extracted, which are denoted by LL_2^α ,LH_2^α ,HL_2^α,HH_2^α and LL_2^β , LH_2^β ,HL_2^β , HH_2^β;

Step2. LH_2 and HL_2 are coded with row traversal method in 2×2 pixel module based onthe rule shown in Eq. (1), where $\Delta_\beta = |\beta_C - \beta'_C|$, $\Delta_\alpha = |\alpha_C - \alpha'_C|$. β_C and α_C are separately for the value of α component and β component in C pixel.α_C' and β_C' are separately for the value of α and β after Eq. (5) calculated. Coding definition is as follows: (1) Based on the embedding rule (Tab.1), there is no change when coding is 00. So the priority of 00 is the highest. Both the bit value of α and β will be modified when the embedded binary code is 11. So the priority of 11 is the lowest. There is no need to code 00 and 11; (2) LH_2 and HL_2 are coded, which are denoted separately by $C_{LH} = t_1', t_2', K, t_k', t_i' \in \{01,10\}$ and $C_{HL} = t_1'', t_2'', K, t_k'', t_i'' \in \{01,10\}$; (3) The final coding of units LH_2 and HL_2 can be get from C_{LH} and C_{HL} ,which can be denoted by $C = t_1', t_1'', t_2', t_2'', K, t_k', t_k'', t_i', t_i'' = t_1, t_2, \ldots, t_n \in \{01,10\}$;

$$C = \begin{cases} 01\,, & \Delta_\beta \le \Delta_\alpha \\ 10\,, & \Delta_\beta > \Delta_\alpha \end{cases} \tag{1}$$

Step3. Logistic mapping of Chaotic map algorithm is used to optimize information, which is defined in Eq. (2). The embedded bit sequence scrambled according to x_k is $C_{IN}^x = b_1^x, b_2^x, K, b_{n-1}^x, b_n^x \in \{00,01,10,11\}$

$$x_{k+1} = \mu x_k (1 - x_k)\,,\ x_k \in (0,1) \tag{2}$$

Step4. In order to optimize the sequence of embedded bits with genetics algorithm,F is supposed as the amount of the same bit value in matched positions betweenC_{IN}^x and C. Optimize x_k using genetic algorithm to maximize F. The optimization model based on CDB-CTT is Eq. (3). The optimal solution y can be obtained by genetic algorithms optimization;

$$F(y) = MaxF(x_k) = Max\sum (t_n \overline{\oplus} b_n^x) \tag{3}$$

Step5. Put y into C_{IN}^x to obtain the optimal embedded bit $C_{IN}^y = b_1^y, b_2^y, K, b_{n-1}^y, b_n^y$. Embed C_{IN}^y alternately into LH_2 and HL_2 with RAID4 row traversal based on Tab 1. Eight bits is the basic data unit of RAID4;

Step6. LL_2 is the most robust region in four CARDBAL2 first-order sub-images. The CDB-CTT embeds the cyclic redundancy check (CRC) of RAID4 (recorded as R^L), and the optimization scrambling parameters y and μinLL_2;

Step7.HH_2 is the most vulnerable region in four sub-images. Embedding the CRC of RAID4 (recorded as R^H) in HH_2. Receiver can judge quickly whether the stego image is attacked ,by comparing R^H and R^L.

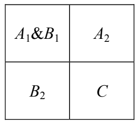


Fig. 2: Chosen of image A and B.

(a) l component (b) α component (c) β component

Fig. 3: $l\alpha\beta$ transform of sub-image.

2.2 The Extracting Information

The process of extracting information can be divided into five steps which are shown as Fig.2:

Step1. Transform the stego image with first-order CARDBAL2 to obtain four sub-images (LL_2, LH_2, HL_2 and HH_2);

Step2. Transform the four sub-images with $l\alpha\beta$ color space transformation and extract α, β ;

Step3. Draw y , μ and R^L from LL_2, and R^H from HH_2;

Step4. It can be indicated that the stego image has not been attacked if $R^L = R^H$. Then the receiver can extract information from LH_2 and HL_2 by y. Thus it can be indicated that the stego image is attacked if $R^L \neq R^H$;

Step5. Extracting information from of LH_2 and HL_2 by using y and R^L .

3 Research Methods

We combine the transform domain-based method called CARDBAL2 with the space domain-based method called $l\alpha\beta$ color space transfer to from the method to pretreat the cover images.

3.1 CARDBAL2 Multi-wavelet Transform

CARDBAL2 transform has distinctive characteristics shown in Fig. 3 the first-order transformation to Lena image and the energy ratio LL_2:LH_2:HL_2:HH_2 of four sub-images is about 1.2:1.1:1.1:1.0 [10].

3.2 Color Transfer Theory

Color Transfer is the new issue in the field of digital image processing. Combine image A with image B to produce image C which has the color characteristics of A

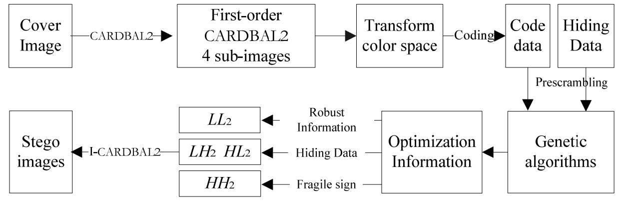


Fig. 4: Embedding process of CDB-CTT.

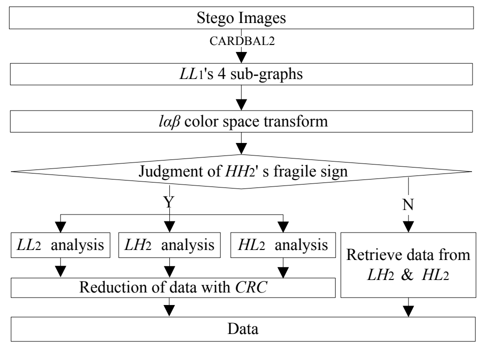


Fig. 5: Extracting process of CDB-CTT.

and the structural shape of B. Our study basis of color transfer theory is $l\alpha\beta$ color space which can analyze the visual information of carrier into quantized information [11]. The biggest advantage is to eliminate the correlation between each color component of RGB. Eq. (4)shows the prinliple of the color transfer theory proposed in [12].

$$\Gamma^* = \frac{\sigma\Gamma_c}{\sigma\Gamma_s}\left(\Gamma_s - \overline{\Gamma_s}\right) + \overline{\Gamma_c} \quad (4)$$

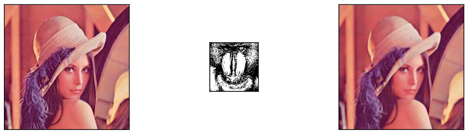
Where Γ is for space component of l, α and β respectively. $\overline{\Gamma_c}$ and $\sigma\Gamma_c$ are separately for mean and standard deviation of l, α and β in color image A.$\overline{\Gamma_s}$ and $\sigma\Gamma_s$ are separately for mean and standard deviation of l, α and β in structure image B. Using the color transfer equation of color transfer theory, generate the embedding rule to modify the data units in order to embed information. Rule1. Fig.4 shows the chosen of image A and B. 2×2 pixel module in space domain is the basic embedding unit. A_1 and A_2 compose color image A. B_1 and B_2 compose structure image B;

Rule2.l is for luminosity.Fig. 5 indicates that l is of the greatest weight in visibility influence compared with α and β;

Based on the weight of $l\alpha\beta$, only modify the α and β component. The modify rules are showed in Eq. (5).

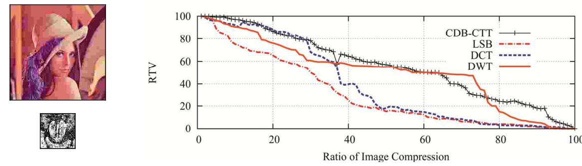
$$\begin{aligned} \alpha'_C &= \frac{\sigma\alpha_A}{\sigma\alpha_B}(\alpha_{B2} - \overline{\alpha_B}) + \overline{\alpha_A} \\ \beta'_C &= \frac{\sigma\beta_A}{\sigma\beta_B}(\beta_{B2} - \overline{\beta_B}) + \overline{\beta_A} \end{aligned} \quad (5)$$

Every basic unit can be embedded with two bits information. The embedding positions are bit α and bit β



(a) Cover image (b) Hiding information (c) Stego image

Fig. 6: Invisibility Experiment.

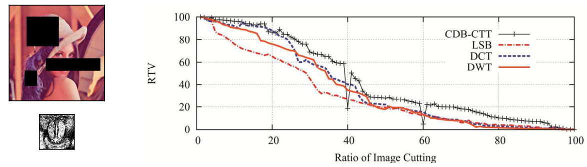


(a) JPEG2000 (59%)(b) RTV results under JPEG2000 compression from 0% to 100%

Fig. 7: JPEG2000 compression experiment.

Table 2: Invisibility comparison based on PSNR.

Scheme	**CDB-CTT**	LSB	DCT	DWT	DWT&DCT	DWT&LSB
PSNR	**36.7799**	25.1258	29.1547	30.0952	31.1124	32.2590



(a) Cutting (22%) RTV results under Cutting from 0% to 100%

Fig. 8: Cutting processing experiment.

of C pixel.Symbol "$\surd$" is represented for no change, and the others are represented modification according to the data in Table1 shown.

4 Results and Discussion

4.1 Safety Performance Analysis

The robustness of information hiding algorithm can be improved by strategy based on features of first-order CARDBAL2 energy distribution, and embedding information in LH_2 and HL_2 with RAID4. Concerning invisibility, firstly, based on the weak relativity of of $l\alpha\beta$ color space, there is no need to consider the change of other dimensionality components when modify random components; Secondly, because 2×2 pixel module is the embedding basic unit, and the final image is the communal area in 2×2 pixel module, the embedding measure can reach 25% and reduce the span of color transfer. Finally, only component α and β are changed, and chaotic map and genetic algorithm are used to reduce the change of cover image. Concerning sensitivity, the feature of CARDBAL2 energy distribution and contrast CRC of RAID4 between LL_2 robustness and fragile sign module are used.Thus CDB-CTT has excellent sensitivity of image processing.

4.2 Simulation Experiment

Lena (256×256) (shown as Fig. 6 (a)) is chosen as the digital image carrier , and binary image Baboon (64×64) (shown as Fig.6 (b)) is considered as the confidential information. And the stego image based on CDB-CTT is shown as Fig.6 (c). In this experiment, PSNR is 36.7799 and this indicates that it is of better invisibility.

Tab.2 shows that the invisibility of CDB-CTT has increased by 24.47% averagely when embedding rate is 25% compared with LSB, DCT and DWT and some developed algorithms.

Table 3: RTV comparison results of filtering and noise.

Attacks	Information hiding algorithm			
	CDB-CTT	LSB	DCT	DWT
[3,3] mean filter / wiener2 filter	**63.37/59.83**	30.58/40.25	50.21/43.26	66.26/57.32
Gaussian /'salt& pepper' noise	**72.75/33.44**	20.15/21.01	60.26/40.21	66.22/29.26

Definition for texture evaluation and modification rate of binary image ($n\times n$ pixels) are separately shown as Eq. (6) and (7),where $n = N/2^k, k \in \{1,2,L,\log_2(N-1)\}$, $f(i,j)$ and $f'(i,j)$ are separately for the pixel at (i,j) of normal and extraction image with $n\times n$ pixels.

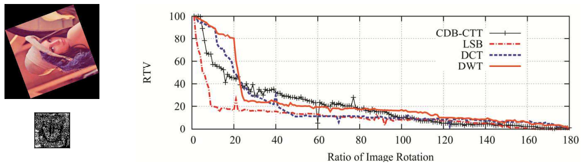
$$w = \frac{n\times n}{\sum\limits_{i=0}^{n-1}\sum\limits_{j=0}^{n-1} f(i,j)\bar{\oplus} f(i\pm 1, j\pm 1)} \tag{6}$$

$$p = \frac{\sum\limits_{i=0}^{n-1}\sum\limits_{j=0}^{n-1} f(i,j)\bar{\oplus} f'(i,j)}{n\times n} \tag{7}$$

Comparison experiments between CDB-CTT and LSB, DCT and DWT are as follows. Robustness test algorithm (RTV) is defined in Eq. (8) and k=4.The extracted information is the most preserved when RTV=100.

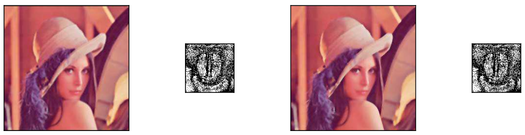
$$Q = w\times p \tag{8}$$

The stego image extracted 59% compression and the confidential information under the JPEG2000 (RTV=57.5842) are shown as Fig. 7 (a). And the RTV values under JPEG2000 compression from 0% to 100% of these four algorithms are shown in Fig.7 (b). The robustness experiment images under other attacks are shown as figures from Fig. 8 to Fig. 11. And the RTV values of CDB-CTT and other comparisons were listed in Tab. 3.



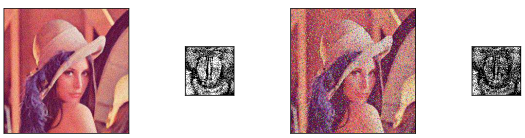
(a) Rotation (110.5°) (b) RTV results under rotation from 0° to 180°

Fig. 9: Rotation processing experiment.



(a) mean filter [3,3] b) wiener2 filter [3,3]

Fig. 10: Filter processing experiment.



(a) Gaussian noise (b) '*salt& pepper*' noise

Fig. 11: Noise processing experiment.

Table 4: Tamper detection rate under different attacks.

Processing	JPEG2000	Cutting	Rotation	Filtering	Gaussian	'salt &
Detectable	97.76%	85.77%	98.65%	97.75%	94.88%	99.07%

Experiments show that CDB-CTT algorithm is robust against JPEG2000 below 71%, cutting below 43%, rotation below 78%, common filtering and adding noise. And show that RTV of CDB-CTT increase by 40.27%, 28.85%, 20.14%, 25.07 and 28.80% separately compared with LSB, DCT and DWT being under attacks such as JPEG2000 compression, cutting, rotation, filter and noise.

Sensitivity to image attacks is the peculiar characteristic in CDB-CTT. Comparing CRC of LL_2 and HH_2 indicates CDB-CTT has excellent sensitivity to image processing. Table 4 lists the detectable rate when JPEG2000 compression ratio is 5%, random cutting ratio is 5%, rotation ratio is 1^0,[3, 3] median filter, Gaussian (μ=0, σ^2=0.003)and 'salt & pepper'(d=0.05).The average of tamper detection rate is 95.65%.

5 Conclusions

Simulation results show that due to the combination of CARDBAL2 and color transfer ,and the induction of chaotic map, genetic algorithm and RAID4, CDB-CTT satisfies the basic requirements of information hiding and also meets the basic security needs of secret information transmission for communication system. It has been proved that this scheme can achieve the less modification of carriers comparing with the other schemes when embedded the same amount data. The future work is focus on choosing of image A and B, embedded module, robustness parameters l and key data in LL_2 .

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