An High Performance Information Hiding Scheme Based on CL multi-wavelet and Color Transfer Theory for Secret Communication

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Abstract: Take advantage of the feature that the energy of the image would gather and spread on four components (LL, LH, HL, and HH) in the sub-image after first-order CL multi-wavelet transform. Make use of the color control ability of I(β) color space in color transfer theory. Propose a reversible information hiding algorithm named as CL-CTT. Use color transfer theory to generate the embedding rule. Embed robust parameters in the LL, hiding information in LH, and HL with RAID4 and fragile sign in HH. Improve the consistence of the embedded data bits’ order and the coding of the sub-image with the chaotic map and the genetic algorithm. Experimental results indicate that CL-CTT can increase imperceptibility by 19.40% averagely and robustness at least 19.99% and have excellent sensitivity of image processing.

Keywords: Algorithms, wavelet transforms, information hiding, CL multi-wavelet transform, color transfer theory, chebyshev chaotic map, genetic algorithm

INTRODUCTION

Information Hiding is an important way to achieve secret communication. The balance between invisibility and robustness in Information Hiding based on digital image becomes a research hotspot. Currently, the space and frequency domain are the main methods of Information Hiding. LSB is the basic algorithm of space domain methods, but the schemes based on LSB almost have drawbacks under embedding great amount of information (Lai and Tsai, 2011). DCT and DWT which are based on frequency domain, have certain robustness but are costly and low robust against rotating attacks (Yuan et al., 2011).

New technologies bring new ideas into Information Hiding. Chui and Lian (1996) proposed CL multi-wavelet transform which can satisfy compact sup-port and symmetry of the image processing. (Li et al., 2005) proposed a color transfer theory which can transfer color from one image to another in the I(β) color space. Using CL multi-wavelet transform technology and color transfer theory, propose an Information Hiding scheme based on CL and color transfer theory: Firstly, transform the cover image with first-order CL multi-wavelet and use four first-order sub-images (LL2, LH2, HL2 and HH2) as information host; Then get the optimal embedded code from the four sub-images; Scramble pre-hiding information with chaotic map (Ye, 2010) and search the optimal scrambled parameters with genetic algorithm (Deb et al., 2002) in order to improve the consistency between pre-hiding information and the best embedded code; Finally, embed hiding information with RAID4 according to embedding rule based on color transfer theory and the optimal scrambled order. Simulation experiment results illustrate that CL-CTT is better than traditional algorithms in invisibility and robustness against image attacks such as JPEG2000, cutting, rotation, filtering and noise. Moreover, the CL-CTT has excellent sensitivity to image attacks.

CL MULTI-WAVELET TRANSFORM

CL multi-wavelet transform is the earliest and most widely used in multi-wavelet transform field, has distinctive characteristics such as compact sup-port, second-order approximation, integer translation and orthogonality of scalar function. Figure 1 shows CL multi-wavelet first-order transformation to Lena image.

Energy ratio of four sub-images after first-order CL Multi-wavelet transform is approximately 284:7:2:1. Based on the feature, embedding region strategy of CL-CTT is as follows: LL2 is robustness module, LH2 and HL2 are data embedded modules and HH2 is a fragile sign module.

COLOR TRANSFER THEORY

Embedded process: Color Transfer is the new issue in the field of digital image processing. Image A and B are
Fig. 1(a-c): First-order CL multi-wavelet transform

combined to produce image C which has the same color characteristics of A and structural shape of B. The biggest advantage of color transfer theory based on $I \alpha \beta$ color space is to eliminate the correlation between each color component of RGB. Equation 1 is the color transfer theory proposed by Marcus and Pierce (1994).

$$\Gamma' = \frac{\sigma_{\Gamma'}^2}{\sigma_{\Gamma}^2}(\Gamma - \Gamma') + \Gamma_c$$

where, $\Gamma$ is for space component of $I$, $\alpha$ and $\beta$, respectively. $\Gamma'$ and $\sigma_{\Gamma'}^2$ are separately for mean and standard deviation of $I$, $\alpha$ and $\beta$ in color image A. $\Gamma$ and $\sigma_{\Gamma}^2$ are separately for mean and standard deviation of $I$, $\alpha$ and $\beta$ 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:

- **Rule 1**: Figure 2 shows the chosen of image A and B. $2 \times 2$ pixel module in space domain is the basic embedding unit. $A_1$ and $A_4$ compose color image A. $B_1$ and $B_4$ compose structure image B.

- **Rule 2**: Is for luminosity. Figure 3 indicates that $I$ is of the greatest weight in visibility influence compared with $\alpha$ and $\beta$.

Based on the weight of $I \alpha \beta$, only modify the $\alpha$ and $\beta$ component. The modify rules are showed in Eq. 2:

$$\alpha'_c = \frac{\sigma_{\alpha'}^2}{\sigma_{\alpha}^2}(\alpha - \overline{\alpha}) + \overline{\alpha}$$

$$\beta'_c = \frac{\sigma_{\beta'}^2}{\sigma_{\beta}^2}(\beta - \overline{\beta}) + \overline{\beta}$$

(2)

Every basic unit can be embedded with two bits information. The embedding positions are $\alpha$ bit and $\beta$ bit.
Fig. 2: Chosen of image A and image B

<table>
<thead>
<tr>
<th>A₁ and B₁</th>
<th>A₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>B₂</td>
<td>C</td>
</tr>
</tbody>
</table>

Table 1. Embedding rule

<table>
<thead>
<tr>
<th>Modified bit</th>
<th>00</th>
<th>01</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>α₀</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>β₀</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

of C pixel. “✓” is for no change and the others represent modifying them to the data in Table 1 shown.

**INFORMATION HIDING SCHEME**

CL-CTT Information hiding scheme has seven steps. Figure 4 shows general process:

**Step 1**: Transform the cover image with first-order CL multi-wavelet and the four sub-images with [αβ] color space. Extract α and β sub-images and denoted by LL₂, LH₂, HL₂, HH₂, LH₃, HL₃, HH₃, LL₅, LH₅, HL₅, HH₅.

**Step 2**: Code LH2 and HL2 with row traversal method in 2 × 2 pixel module based on the rule shown on Eq. 3. Where \( \Delta_\alpha = |\beta_\alpha - \beta'_\alpha| \), \( \Delta_\beta = |\alpha_\beta - \alpha'_\beta| \), \( \alpha_\beta \) and \( \beta_\beta \) are separately for the value of α component and β component in C pixel. \( \alpha'_\beta \) and \( \beta'_\beta \) are separately for the value of α and β after Eq. 2 calculated.

Coding definition as follows Eq. 1. Based on the embedding rule (Table 1), there is no change when coding is 00. So, the priority of 00 is the highest. Modify the components both α and β when coding is 11. So, the priority of 11 is the lowest. There is no need to code 00 and 11, Eq. 2 Code LH₂ and HL₂ and denoted separately by \( C_{\text{LH}} = t_{01}, t_{02}, \ldots, t_{10}, t_{11} \in \{01, 10\} \) and \( C_{\text{HL}} = t'_{01}, t'_{02}, \ldots, t'_{10}, t'_{11} \in \{01, 10\} \), Eq. 3 Get the final coding of units LH₂ and HL₂ from \( C_{\text{LH}} \) and \( C_{\text{HL}} \) denoted by \( C_{\text{LH}} = t_{01}, t'_{02}, t_{03}, t_{04}, t_{05}, t'_{06}, t_{07}, t'_{08} \in \{01, 10\} \):

\[
C = \begin{cases} 
01, & \Delta_\alpha \leq \Delta_\beta \\
10, & \Delta_\beta > \Delta_\alpha 
\end{cases} 
\]  

\[(3)\]

**Step 3**: Use Logistic mapping of Chaotic map algorithm to optimize information, as defined in Eq. 4. Suppose the bit series scrambled according to \( \mu \) and \( x_0 \) is

\[
C_{\text{NL}} = b_{\text{01}}, b'_{\text{02}}, \ldots, b'_{\text{11}}, b_{\text{12}}, \ldots, b'_{\text{11}}, \in \{00, 01, 10, 11\} \\
X_{\text{NL}} = \mu X_{\text{NL}}(1 - X_{\text{NL}}), X_{\text{NL}}(0, 1) \]  

\[(4)\]

**Step 4**: In order to optimize the sequence of embedded bits with genetics algorithm, suppose F as the amount of the same bit value in matched positions between \( C_{\text{NL}} \) and C. Optimize \( x_0 \) using
genetic algorithm to maximize $F$. The optimization model based on CL-CTT is Eq. 5. Where $\oplus$ is for XOR. Get the optimal solution $y$ by genetic algorithms optimization:

$$ F(y) = \text{Max} F(x_i) = \text{Max} \sum (t_i \oplus b^*_{i}) \quad (5) $$

**Step 5:** Put $y$ into $C_{8r}$ to obtain the optimal embedded bit $C_{8r} = b_1^*, b_2^*, \ldots, b_{8r}^*$. Embed $C^r$ alternately into LH1 and HL1 with RAID4 row traversal based on Table 1 listed. Eight bits is the basic data unit of RAID4.

**Step 6:** LL1 is the most robust region in four CL first-order sub-images. The CL-CTT embeds the cyclic redundancy check (CRC) of RAID4 (recorded as $R^c$), the optimization scrambling parameters $y$ and $\mu$ in LL1.

**Step 7:** HH1 is the most vulnerable region in four sub-images. Embedding the CRC of RAID4 (recorded as $R^c$) in HH2. Receiver can judge quickly by comparing $R^c$ and $R^c$ whether the stego image is attacked.

Extracting Information: Extracting information is divided into five steps as shown in Fig. 5:

**Step 1:** Transform the stego image with first-order CL to obtain four sub-images (LL1, LH1, HL1, and HH1)

**Step 2:** Transform the 4 sub-images with log color space transformation and extract $x_i, y_i$ sub-images

**Step 3:** Draw the $y_i, \mu$ and $R^c$ from LL1, and $R^c$ from HH1

**Step 4:** It can be indicated that the stego image has not been attacked if $R^c = R^c$. Then receiver can extract information from LH1 and HL1 by parameters $y$. It can be indicated that the stego image is attacked if $R^c \neq R^c$.

**Step 5:** Extracting information from of LH1 and HL1 by using $y$ and $R^c$.

**SAFETY PERFORMANCE ANALYSIS**

Concerning robustness, It can be improved by proposing strategy based on features of first-order CL energy distribution and embedding information in LH1 and HL1 with RAID4. Concerning invisibility, firstly, based on the weak relativity of log color space, there is no need to consider the change of other dimensionality components when modify random components; Secondly, because $2 \times 2$ pixel module is the embedding basic unit, the final image is the communal area in $2 \times 2$ pixel module, the embedding measure can reach 25% and reduce the span of color...
transfer; Finally, only change $\alpha$ and $\beta$ component and use chaotic map and genetic algorithm to reduce the change of cover image. Concerning sensitivity, use the feature of CL energy distribution and contrast CRC of RAID4 between LL, robustness and fragile sign module. CL-CTT has excellent sensitivity of image processing.

**SIMULATION EXPERIMENT**

Simulation environment is MATLAB 7.0.0.19920. Cover image is Lena $(256\times256)$ (Fig. 6a). Stego image is binary image baboon $(64\times64)$ (Fig. 6b). Figure 6c shows stego image based on CL-CTT. PSNR = 35.2823 and indicates that it is of better invisibility. Table 2 shows invisibility of CL-CTT increases by 19.40\% averagely when embedding rate is 25\% compared with LSB, DCT and DWT and some developed algorithm.

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

$$w = \frac{n \times n}{\sum_{i=1}^{n-1} \sum_{j=1}^{n-1} f(i, j) \oplus f(i \pm 1, j \pm 1)}$$

$$p = \frac{\sum_{i=1}^{n-1} \sum_{j=1}^{n-1} f(i, j) \oplus f'(i, j)}{n \times n}$$

**Table 2: Invisibility comparison based on PSNR**

<table>
<thead>
<tr>
<th>Scheme</th>
<th>CL-CTT</th>
<th>LSB</th>
<th>DCT</th>
<th>DWT</th>
<th>DWT and DCT</th>
<th>DWT and LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSNR</td>
<td>35.2823</td>
<td>25.1258</td>
<td>29.1547</td>
<td>30.0952</td>
<td>31.1124</td>
<td>32.2590</td>
</tr>
</tbody>
</table>

**Table 3. RTV comparison results of filtering and noise**

<table>
<thead>
<tr>
<th>Attacks</th>
<th>Information hiding algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CL-CTT</td>
</tr>
<tr>
<td>[3, 3] mean filter/wiener2 filter</td>
<td>62.44/58.54</td>
</tr>
<tr>
<td>Gaussian'salt and pepper noise</td>
<td>71.45/32.76</td>
</tr>
</tbody>
</table>

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

$$Q = w \cdot p$$ (8)

Figure 7a shows image under the JPEG2000 57\% compression and image rebuilt (RTV = 56.0631). Figure 7b shows the RTV of every algorithm under JPEG2000 compression from 0-100\%.

Figure 8a shows image under the cutting 20\% and image rebuilt (RTV = 88.8639). Figure 8b shows the RTV of every algorithm under cutting processing from 0-100\%.

Figure 9a shows image under the rotation $110.5^\circ$ and image rebuilt (RTV = 11.2268). Figure 9b shows the RTV of every algorithm under rotation processing from 0-180\%.

Figure 10a shows image under the mean filter [3, 3] and image rebuilt. Figure 10b shows image under the wiener2 filter [3, 3] and image rebuilt. Table 3 lists the RTV of CL-CTT and other algorithm.

Figure 11a shows image under the Gaussian noise ($\mu = 0, \sigma^2 = 0.003$) and image rebuilt. Figure 11b shows image under the 'salt and pepper' noise ($d = 0.15$) and image rebuilt. Table 3 lists the RTV of CL-CTT and other algorithm.

Experiment show that CL-CTT algorithm is robust against JPEG2000 below 72\%, cutting below 47\%, rotation below 75\%, common filtering and adding noise. And show that RTV of CL-CTT increase by 40.02, 28.65,
Fig. 7(a-b): JPEG2000 compression experiment (a) JPEG2000 (57%) and (b) RTV results under JPEG2000 compression from 0-100%.

Fig. 8(a-b): Cutting processing experiment (a) Cutting (20%) and (b) RTV results under Cutting from 0-100%.

Fig. 9(a-b): Rotation processing experiment (a) Rotation (110.5°) and (b) RTV results under rotation from 0-180°.

Fig. 10(a-b): Filter processing experiment (a) mean filter [3, 3] and (b) wiener2 filter [3, 3].

Fig. 11(a-b): Noise processing experiment (a) Gaussian noise and (b) ‘salt and pepper’ noise.
19.99, 24.97 and 28.60% 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 CL-CTT. Comparing CRC of LL2 and HH2 indicates CL-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°, [3, 3] median filter, Gaussian (μ = 0, σ2 = 0.003) and ‘salt and pepper’(d = 0.05). The average of detectable rate is 94.03%.

<table>
<thead>
<tr>
<th>Processing</th>
<th>JPEG2000 (%)</th>
<th>Cutting (%)</th>
<th>Rotation (%)</th>
<th>Filtering (%)</th>
<th>Gaussian (%)</th>
<th>'Salt and pepper' (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detectable rate</td>
<td>89.22</td>
<td>87.01</td>
<td>99.29</td>
<td>96.97</td>
<td>93.05</td>
<td>98.63</td>
</tr>
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</table>

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CONCLUSION

In conclusion, Simulation results show that due to the combination of CL multi-wavelet and color transfer and induction of chaotic map, genetic algorithm and RAID4, CL-CTT satisfies information hiding and also meets the basic security needs of secret information transmission for communication system. The future work is focus on choosing image A and B, embedded module, robustness parameters I and key data in LL2.

REFERENCES