DIGITAL IMAGE STEGANOGRAPHY ALGORITHM BASED ON ITERATIVE BLENDING

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ABSTRACT

A novel image steganography algorithm in wavelet domain is presented using the iterative blending method. Using this algorithm, we can hide a secret image with 256 gray levels into another carrier image. By taking full advantage of the masking characters of human visual system, a JND (just noticed difference) threshold matrix is given pixel by pixel in the image subbands taking into account the texture and the luminance content of carrier image. The secret image is divided into tow matrixes to make the gray level no more than 16. Then the matrixes are adaptively embedded into the wavelet coefficients of the carrier image by iterative blending. The carrier image and the blending parameter can act as the private keys. The experimental results show that the proposed algorithm provides good transparency and is robust to some extent. The technique also can be used in digital watermarking and other digital application areas.

1. INTRODUCTION

Information hiding, an old and interesting technology, embeds data into digital media for the purpose of identification, annotation, and copyright. In recent years, making use of the masking character of human visual system to enhance hiding imperceptibility and security has been wildly used in one branch of information hiding: perceptual watermarks[1]. Perceptual watermarks exploit the human visual system to decide the upper bounds of embedding in the carrier. Then under the bounds they max the strength of watermarks in order to provide robustness to attacks. Kankanhalli [1] proposes a way of calculating a just notice distortion mask for the image in the DCT domain based on the local region image content; Watson [2] shows how to compute a visually optimal 8×8 DCT quantization matrix based on the masking of frequency, luminance and contrast. Watson [4][5] proposes a mathematical mode for DWT noise detection thresholds and measures a quantization matrix based on the Antonini wavelet; Basing on above two visual models, Podilchuk proposes two perceptual watermarking schemes, IA-DCT, IA-W, both are good in terms of image transparency and robustness; In [7]. Kundur extends the visual model given by Dooley [8] to get the measure of the importance of an image components and used it as the watermark embedding strength. In [9], watermark masking in the wavelet domain is accomplished pixel by pixel by taking into account the texture and the luminance content of all the image subbands and the watermark is embedded into the wavelet coefficients. In [10], first a JND (just noticed difference) threshold matrix based on block is given, and then a robust image-adaptive public watermarking technique operating in DWT domain is presented. In this paper, we use this visual model in [9] and we'll describe it below.

In above methods the watermarks are almost pseudorandom sequence or modulated pseudo-random numbers, and have no meanings. Although, in[10], a binary image is embedded as watermark, but only 1 bit is embedded in every 8×8 block. So the capacity is not enough for 256 gray image. In this paper, making full use of the characters of human visual system, we embed a gray image as the secret information into a still gray image. Given its excellent spatio-frequency localization properties and suitability to model the HVS behavior, the DWT is used to carrier image. Then the JND threshold matrix in wavelet domain is calculated. After that, the secret images is embedded adaptively into carrier image by iterative blending methord. In section 2, we describe the calculation of JND threshold matrix; In section 3, we describe our iterative blending algorithm; the experiments results are given in section 4; At last in section 5, we get conclusions.

2. JND (JUST NOTICED DIFFERENCE) THRESHOLD

In order to deter where to embed the secret information and the strength of the embedding, we would explore the character of human visual system. In their work of image compression [11], Lewis and Knowles study the JND threshold of wavelet coefficients, Barni [9] extends this work to get a visual model as follow: First the carrier image is decomposed through DWT in four levels. Lets us call I_l^θ the subband at resolution level $l = 0,1,2,3$ and with orientation $\theta = 0,1,2,3$ (see figure 1).

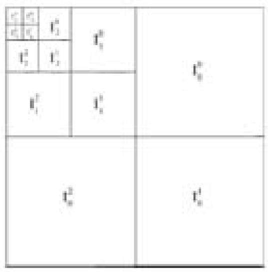


Fig. 1. Sketch of the decomposition of an image in four resolution levels through the DWT.

(1) The eye is less sensitive to noise in high resolution bands and in those bands having orientation of 45° (i.e., $\theta = 1$ bands in our case). Let $\Theta(l,\theta)$ represent the masking of noise depending on different subbands of different orientation.:

$$\Theta(l,\theta) = \begin{Bmatrix} \sqrt{2} & if \theta = 1 \\ 1 & otherwise \end{Bmatrix} \cdot \begin{Bmatrix} 1.00 & if\ l = 0 \\ 0.32 & if\ l = 1 \\ 0.16 & if\ l = 2 \\ 0.10 & if\ l = 3 \end{Bmatrix} \quad (1)$$

(2) The eye is less sensitive to noise in those areas of the image where brightness is high or low. We compute this factor in the following way:

$$\Lambda(l,i,j) = 1 + L'(l,i,j) \quad (2)$$

$$L'(l,i,j) = \begin{Bmatrix} 1 - L(l,i,j) & if\ L(l,i,j) < 0.5 \\ L(l,i,j) & otherwise \end{Bmatrix} \quad (3)$$

$$L(l,i,j) = \frac{1}{256} I_3^3 \left(1 + \left\lfloor \frac{i}{2^{3-l}} \right\rfloor, 1 + \left\lfloor \frac{j}{2^{3-l}} \right\rfloor \right) \quad (4)$$

(3) The eye is less sensitive to noise in highly textured areas but among these, more sensitive near the edges. The masking factor of texture is $\Xi(l,i,j)$:

$$\Xi(l,i,j) = \sum_{K=0}^{3-l} \frac{1}{16^K} \sum_{\theta=0}^{2} \sum_{x=0}^{1} \sum_{y=0}^{1} \left[I_{K+l}^{\theta} \left(y + \frac{i}{2^K}, x + \frac{j}{2^K} \right) \right]^2 \quad (5)$$
$$\cdot Var \left\{ I_3^3 \left(1 + y + \frac{i}{2^{3-l}}, 1 + x + \frac{j}{2^{3-l}} \right) \right\}_{\substack{x=0,1 \\ y=0,1}}$$

So the JND (just noticed difference) threshold matrix given as following:

$$JND_l^\theta(i,j) = \Theta(l,\theta) \Lambda(l,i,j) \Xi(l,i,j) / 2 \quad (6)$$

3. A NOVEL STEGANOGRAPY ALGORITHM

In this section, we'll describe the novel digital image steganography algorithm. First we'll introduce the iterative blending method of image.

3.1. Blending of Digital Images in Spatial Domain[12]

Zhang [12] introduces the blending of digital images in spatial domain.

Definition 1 : F and G are digital images with size M×N, $\{\alpha_i \mid 0 \le \alpha_i \le 1, i = 1,2,\cdots,n\}$ are n real numbers, blend image F and G with parameter α_1 to get $S_1 = (1-\alpha_1)F + \alpha_1 G$, blend image F and S_1 with parameter α_2 to get $S_2 = (1-\alpha_2)F + \alpha_2 S_1$, blend in turn to get $S_n = (1-\alpha_n)F + \alpha_n S_{n-1}$, then digital image S_n is called the nth blending of F and G with parameter α_i .

We can let F be the carrier image, G be secret image then S_n is the stego-image. According to above definition, we obtain the following:

Theorem 1 if $\alpha_1 = \alpha_2 = \cdots = \alpha_n = \alpha$, then:

$S_n = (1 - \alpha^n)F + \alpha^n G$.

Proof : when n=1, $S_1 = (1-\alpha)F + \alpha G$;

If : $n = m - 1$, $S_{m-1} = (1-\alpha^{m-1})F + \alpha^{m-1}G$,

then : when $n = m$

$$S_m = (1-\alpha)F + \alpha S_{m-1} = (1-\alpha)F + \alpha(1-\alpha^{m-1})F + \alpha^m G$$
$$= (1 - \alpha + \alpha - \alpha^m)F + \alpha^m G = (1-\alpha^m)F + \alpha^m G$$

So, the theorem is proven.

Theorem 2 S_n is the nth blending of digital image F and G with parameter $\{\alpha_i \mid 0 \le \alpha_i \le 1, i = 1,2,\cdots,n\}$, $\alpha_1 = \alpha_2 = \cdots = \alpha_n = \alpha$,when $\alpha_i (i = 1,2,\cdots,n)$ is neither 0 nor 1, then S_n is monotonously convergent to F, that is $\lim_{n\to\infty} S_n = F$.

Proof : From Theorem 1, $S_n = (1-\alpha^n)F + \alpha^n G$, when $0 < \alpha < 1$ and $n \to \infty$, then $\lim_{n\to\infty} S_n = F$.

So, the theorem is proven.

According to the above conclusion, combining with the model of human visual system, we propose the algorithm of image iterative blending in wavelet domain.

3.2. Image Iterative Blending in Wavelet Domain

Our algorithm divides in following steps:

(1) Decompose the carrier image through DWT in four levels, then calculate the JND threshold of wavelet coefficients as described in section 2;

(2) We divided the secret image (suppose it's size is $M_2 \times N_2$) into two matrixes to let the pixel gray value of the new matrixes is less than 16. For example, in the secret image a pixel gray value is 165, expressing in binary is 10100101. We take out the odd bits and even bits separately to compose two 4 bits binary, in this case, they are 0111 and 1100. Then we decimalize them to get 7 and 12. After decomposing every pixel in secret image, we get two matrixes A_1 , A_2 with the same size of the secret image and the pixel value is less than 16.

(3) From the subbands of carrier image after DWT, we chose the two subbands with $l = 0$ and $\theta = 0,2$ (see figure

(1). Then from the two chosen subbands, we chose $M_2 \times N_2$ wavelet coefficients separately which have the largest $JND_l^\theta(i,j)$ in the subbands to compose two matrixes O_1 and O_2 for embedding of data .

(4) Blend A_1 into O_1, and A_2 into O_2 iteratively with an initial blending parameter. We use $JND_l^\theta(i,j)$ as the threshold. In blending process, when the change is exceed the $JND_l^\theta(i,j)$, the blending parameter will be decreased, and blending will be do again until the change is below the JND threshold. The pseudo code of the progress is described below:

```
        Input O_i , A_i , S = A_i
        Get a blending parameter α , 0 < α < 1 ,
L10:    β = 1 − α
        S = β · O_i + α · S
        W = S − O_i
        while ( W(i, j) > JND_l^θ (i, j) )
              α = α · α
              goto  L10
        end
              α_i = α
              output S ,  α_i
```

S is the blending matrix , α_i is the blending parameter.

(5) After iterative blending, we get blending matrixes S_1, S_2 .Put S_1, S_2 back to the wavelet coefficients of the carrier image, and do the reverse DWT to get the stego-image.

3.3. Extraction of Secret Image

Extraction of secret image is the reverse process of embedding. We suppose the legal accepter has the original carrier image and the blending parameter α_1, α_2 (that can be obtain through other channel). The steps of extraction are:

(1) Chose the matrixes O_1, O_2 from the subbands of original carrier image as described in embedding step 1,3

(2) Decompose the stego-image through DWT, then chose the wavelet coefficients as the same place as O_1, O_2 from the two subbands of stego-image with $l = 0$ and $\theta = 0{,}2$ to compose matrixes S_1, S_2.

(3) According to Theorem 1, we can obtain the following :

$$A_1' = \frac{S_1 - (1-\alpha_1)O_1}{\alpha_1}$$
$$A_2' = \frac{S_2 - (1-\alpha_2)}{\alpha_2} \qquad (7)$$

In above formula, α_1, α_2 are the blending parameter, A_1', A_2' are the extracted matrixes composed by the odd bits and even bits of the pixel values of secret image.

(4) According to the reverse process of embedding step 2, compose A_1', A_2' to get the secret image E . For example, if a pixel value $p_1(i,j)$ (i,j is the coordinates) in A_1' is 7 (expressed in binary is 0111), the pixel value $p_2(i,j)$ in the same place in A_2' is 12 (expresses in binary is 1100). Compose these tow number to get pixel value $p(i,j)$ in E that is 10100101. So we can extract the secret image.

In order to measure the transparency of our algorithm, we use the PSNR (Peak Signal-to-Noise Ratio) as the measurement of similarity of two images:

$$PSNR = 10 \log_{10}\left[\frac{M \times N}{\sum_{i=1}^{M}\sum_{j=1}^{N}(F(i,j) - S(i,j))^2}\right] \qquad (8)$$

In the above formula F, S is two images with the size of $M \times N$.

4. EXPERIMENT RESULT

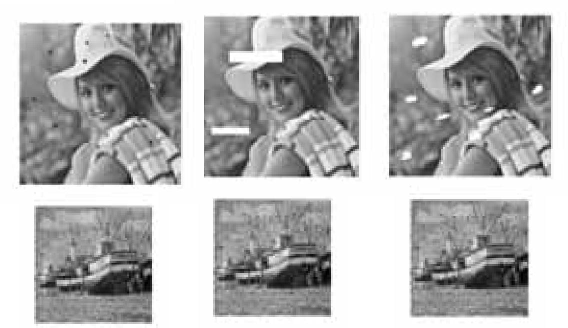
Using our hiding algorithm, we embed a 128×128 gray image into different three carrier images. The carrier images are 512×512 gray images (see figure 2). The secret image is shown in figure 3. The initial value of blending parameter α is 0.6.

The experiment results show that we can retrieve the secret image from the stego-image without error. In figure 2, the left are the original carrier images, the middle are the stego-images, the right are the difference images of the stego-images and the carrier images (the difference images are amplified 30 times absolutely). From figure 2, we can see that the stego-images look no difference from the carrier images in visual. That shows the good transparency of the algorithm. From the difference images, we can see that the data is almost embedded in highly texture region, high light region and very dark region. In the smoothing region and middle light region, there is little change. Table 1 lists the last value of blending parameter α_1, α_2 and the iterative times. We can see the embedding strength is adaptive to the JND threshold. Figure 4 shows the result of robustness experiment. We add spots in the stego-image, cut it using rectangle, and cut it irregularly. The stained stego-images are shown in the top row in figure 4 with the corresponding extracted secret images shown in the below. The PSNR values of the extracted secret images with the original secret image are shown below the extracted images. The result shows that the algorithm can resist attacks to some extent.

(a) carrier images (b) stego-images (c) difference images (amplified 30 times)

Fig.2. experiment results of embedding

Fig. 3 . secret image



$PSNR = 49.5484$ $PSNR = 45.206$ $PSNR = 47.1425$

Fig. 4. the result of robustness experiment

Table 1. the results of experiment

Image	Cameraman	Autumn	Elaine
PRSN	**39.9**	**40.352**	**33.77**
α_1	**0.36**	**0.2126**	**0.6**
Iterative times	**2**	**3**	**1**
α_2	**0.2126**	**0.36**	**0.6**
Iterative times	**3**	**2**	**1**

5. CONCLUSION

Information hiding is a hot interest area recently in the research of information security. In this paper, using the character of human visual system we propose a iterative blending algorithm to hiding a gray image in another gray image. Experiment results show that the hiding effect and retrieving effect is good. The algorithm also can resist some attack to some extent. In order to improve the security, we can do some pretreatment before embedding such as permutation of the secret image. Our algorithm can be applied in color image and digital watermark also.

6. REFERENCES

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