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Steganographic Embedding in JPEG Images with Visual Criterion

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***Abstract*—In this paper, we present a new information hiding scheme in JPEG images to achieve a good embedding efficiency considering visual criterion. We construct an embedding impact model based on human visual system, and then assign each cover element a flipping cost which would be the key parameter during the embedding procedure. In this way, the proposed method can minimize the total embedding impact via Viterbi algorithm, meanwhile improve the visual quality of the stego medium. The experimental results later show that the proposed information hiding system can perform well in different types of images.**

Keywords-steganography; visual quality; embedding impact

I. INTRODUCTION

Recent years, research on data hiding is becoming important for protecting the confidential information. In data hiding, especially steganography, the secret messages are embedded imperceptibly into cover files (such as digital images, audios, and videos) by slightly modifying some of the cover elements (pixels, DCT coefficients, etc.). The media with the embedded secret known as the stego medium must appear to be similar to its original so that the stego medium cannot arouse suspicion. However, the anti-data hiding research has also rapidly developed to detect the presence of secret messages based on revealing visual or statistical abnormalities in the stego medium. Generally speaking, the more the embedded data, the more vulnerable the system will be to the anti-data hiding attempts.

Stego-encoding techniques can reduce the number of alterations to the cover signal for hiding the same quantity of data, thus improving embedding efficiency. For example, using syndrome codes combined low-density generator matrices (LDGMs) [1] and stego-code families (SCF) [2], a practical binary embedding technique [3] is designed and its rate-distortion performance is currently the closest to the theoretical limit [4]. In [5], the fast BCH coding can reduce both time complexity and storage complexity compared to the existed methods. In exploiting modification direction (EMD) method [6], each secret digit in a $(2n+1)$-ary notational system can be carried by n cover pixels and, at most, only one pixel is changed. Assuming that all cover elements have the same contribution to the whole image display, these above stego-encoding methods can decline the embedding distortion and achieve high embedding efficiency. However, the embedding impacts of each flipped cover element can't be considered the same, and they are very relevant to the image display, especially visual quality.

Embedding impact, in other word, distortion effect due to flipping depends on the cost of making an embedding change at the cover element. The traditional distortion models like constant profile are image-independent and consider each element of the cover having the same impact on detectablity when changed. As we all know, different mean luminance values of the parts have different detection threshold. Thus, we should avoid modifying the parts of cover which would cause significant visual distortions.

In this paper, we construct a human visual embedding impact model for the cover object which is based on Watson's work [7] in the first place, that is, each individual element of the cover has its modification cost concerned cover content. After, we hope to create a practical algorithm such that the total embedding cost is minimal, here, we develop the Viterbi algorithm for its excellent embedding efficiency in several simple known embedding cost models, i.e., constant profile, the linear profile, and the square profile [8]. This novel steganography scheme can not only achieve a good embedding efficiency performance but also guarantee a high visual quality.

II. PROPOSED SCHEME

As JPEG image is a widespread digital image format on Internet, our work focuses on the secure steganographic schemes of JPEG images. We modify DCT coefficients of the JPEG image to hide information. Each DCT coefficient has been assigned a changing cost value provided by our embedding impact model. The proposed steganographic algorithm ensures a near-optimal embedding efficiency, i.e. the total embedding impact could be minimal as far as possible.

A. HVS Embedding Impact Model

This section gives human visual embedding impact model based on the concept of just noticeable differences (JND) [7], which can capture both threshold effects and spatial-frequency sensitivity of the HVS. Fusions of luminance masking, contrast masking and pooling, JND can reflect the largest modification value under the unawareness

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of human eye. The cost of a flipping at one pixel when embedding, ρ, could be computed as follow:

- Get the DCT coefficients of the cover image by block $C_{i,j,k}$, where i, j ($0 \le i, j \le 7$) index the DCT frequency in the individual block, and k indexes the block number.
- Compute the luminance masking of every DCT coefficient,

$$t_{i,j,k} = t_{i,j} \cdot (c_{0,0,k} / \bar{c}_{00})^{a_T} , \tag{1}$$

where $t_{i,j}$ should be made a assuming display luminance, and initial values are shown in Table1; $c_{0,0,k}$ is the DC coefficient of the k-th block, which represents the average brightness of the block k; $\bar{c}_{00}$ is the DC coefficient, which represents the average brightness of whole image; and a_T controls the degree to which this masking occurs, where in it suggests 0.649 [7]. Equation (1), we can find the higher the average brightness of image blocks are, the greater the luminance masking, $t_{i,j,k}$, is.

TABLE I. FREQUENCY PERCEPTION TABLE

1.40	1.01	1.16	1.66	2.40	3.43	4.79	6.56
1.01	1.45	1.32	1.52	2.00	2.71	3.67	4.93
1.16	1.32	2.24	2.59	2.98	3.64	4.60	5.88
1.66	1.52	2.59	3.77	4.55	5.30	6.28	7.60
2.40	2.00	2.98	4.55	6.15	7.46	8.71	10.17
3.43	2.71	3.64	5.30	7.46	9.62	11.58	13.51
4.79	3.67	4.60	6.28	8.71	11.58	14.50	17.29
6.56	4.93	5.88	7.60	10.17	13.51	17.29	21.15

- Calculate the contrast masking, $m_{i,j,k}$, with the above $t_{i,j,k}$,

$$m_{i,j,k} = \max[t_{i,j,k}, |c_{i,j,k}|^{w_{i,j}} \, t_{i,j,k}^{1-w_{i,j}}] , \tag{2}$$

here, $w_{i,j}$ is an exponent that lies between 0 and 1, and a typical empirical value is 0.7. Obviously, contrast masking effect on the different band of image is different, and it depends on the different band information contained. The equation (2) is widely used in vision models, which indicates that, the smaller the value of $m_{i,j,k}$ is, the more sensitive human eye on the frequency would be, i.e., the higher the cost of modifying the carrier element is. Therefore, we should avoid modifying the carrier elements with smaller value $m_{i,j,k}$.

- Finally, we can get the formula of ρ,

$$\rho_{i,j,k} = 1 / m_{i,j,k} , \tag{3}$$

the $\rho_{i,j,k}$ means the embedding impact caused by flipping the cover element $C_{i,j,k}$ for data hiding. When the value of $\rho_{i,j,k}$ is bigger, the distortion caused by modifying $C_{i,j,k}$ is greater.

B. Data Embedding Procedure

Assuming binary embedding operation, let sequence $\mathbf{s} = (s_1, s_2, ..., s_m) \in \{0,1\}^m$ be secret messages, and $\mathbf{x} = (x_1, x_2, ..., x_n) \in \{0,1\}^n$ ($m < n$) be elements of cover object, here, we use least significant bit (LSB) of DCT coefficients to embed the secret messages. After slightly modifying some of elements in $\mathbf{x}$ for hiding $\mathbf{s}$, stego object $\mathbf{y}$ is produced, that is, $\mathbf{y} = (y_1, y_2, ..., y_n) \in \{0,1\}^n$.

We also define the function of total embedding impact $D(x, y)$,

$$D(x,y) = \|x - y\|_\rho = \sum_{i=1}^{n} \rho_i |x_i - y_i| , \tag{4}$$

where $\rho_i \in [0, \infty)$ is a cost of changing i-th ($0 \le i \le n$) cover element. The details about ρ have been discussed in section 2.1. Thus, our method is aimed to embed m bits in n cover element such that $D(x, y)$ is minimal.

Fig. 1 shows the proposed embedding procedure. Here, we just use the JPEG image as cover image. The cover stream $\mathbf{x} \in \{0,1\}^n$ derived from the LSB of DCT coefficients, except the DC and zero ones. For security consideration, the DC and zero ones should avoid flipping during the information hiding. We can get the embedding impact $\rho_{i,j,k}$ of each element in cover with DCT coefficient $C_{i,j,k}$ from (2) and (3).

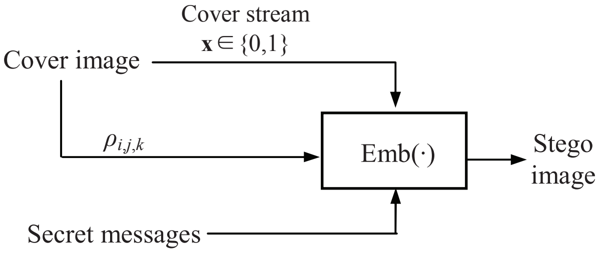

Figure 1. Framework of the data embedding procedure

Then, we begin to embed the secret sequence $\mathbf{s}$ by modifying the cover stream $\mathbf{x}$ which is shown in the central part of the Fig. 1.

The relation between secret messages $\mathbf{s}$ and stego medium $\mathbf{y}$ can be expressed as matrix form as (5),

$$\mathbf{H}\mathbf{y}^T = \mathbf{s}^T . \tag{5}$$

Firstly, we need to construct a good and practical parity-check matrix $\mathbf{H}$ sized $m \times n$, which means $\mathbf{H}$ should be easily generated and restored. In this paper, $\mathbf{H}$ can be generated by a small sub matrix $\mathbf{H}^s$ of size $h \times w$ [8]. Here, the height h of $\mathbf{H}^s$ is called the constraint height (in the pseudo code, h=10), and the width w equals to $1/\alpha$ where α is the embedded rate.

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$$\alpha = m / n \, , \qquad (6)$$

where m is the length of message bits, n is the length of cover elements.

After that, according to the above, the parity-check matrix **H** and secret message **s** are known in the procedure of data embedding, however, it is very difficult to calculate the stego-object **y** directly via (5), and here, we use syndrome-trellis codes [8] to get **y**. The STC form a class of convolutional codes, which can be described as trellis. We turn the cover stream into a simple trellis, consisting of b blocks, each block containing $2h\times(w+1)$ nodes organized in a grid of $w+1$ columns and $2h$ rows. Each block we use edges to connect two adjacent columns. And all edges have a weight of ρ (our imbedding impact model), except for the horizontal ones (which having a weight of 0 means no modification during embedding messages). Each **y** satisfying (5) is represented as a path through the trellis from the leftmost to the right. The well-known Viterbi algorithm can find the path which has the minimal total cost D and is also closer to the original cover **x**. More details about Viterbi algorithm are provided by [8]. Our embedding scheme can satisfy both (5) and minimal $D(x, y)$.

Finally, we would get the stego image. In addition, such an embedding manner needs the matrix **H** for data extraction. So we must secretly transmit sub matrix $\mathbf{H}^s$ as a design parameter to the receiver end through some agreed available channel. One simple idea is to preserve these extra bits into the LSBs of the first 8×8 cover block by LSB replacement.

Actually our method belong to "±1 embedding" [9] by arbitrarily choosing adding or subtracting one from the LSB place of DCT coefficients. In order to extract secret correctly, if the DCT value $c = 1$ needs to be modified, only one modification +1 is permitted; similarly, if $c = -1$ needs to be modified, only -1 is permitted.

C. *Data Extraction Procedure*

On the receiving side, we can gain the stego stream **y** derived from the LSB of DCT coefficients, still except the DC and zero quantized ones. These Design parameters ($\mathbf{H}^s$, m, n, h) can also be extracted from the stego image. After, we can reconstruct the parity-check matrix **H** by the small submatrix $\mathbf{H}^s$ and (m, n, h). At last, a simple calculation of (5) would help to recover the hidden messages.

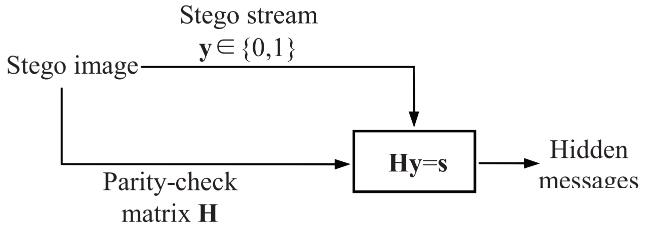
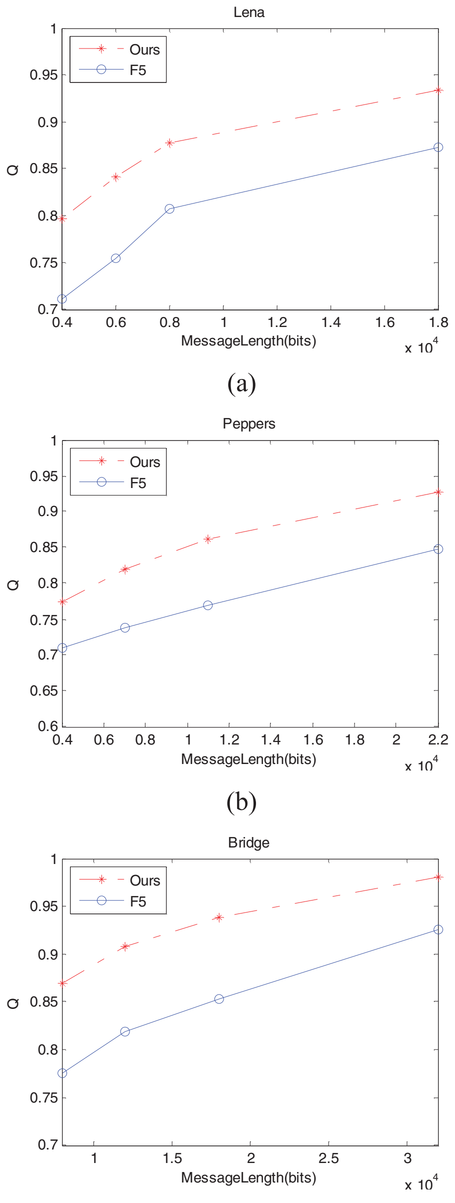


Figure 2. Framework of the data embedding procedure

III. EXPERIMENTAL RESULTS

In terms of embedding capacity and distortion, the performance of our method is measured by comparing with the F5 algorithm [10]. Usually there are several approaches to measure the distortion or image quality induced by data embedding, such as peak signal to noise ratio (PSNR), root mean squared error (RMSE). But these simple mathematically defined metrics in the literature are image-independent without consideration of the HVS characteristics, here, we use the universal quality index (short Q) [11] which performs significantly over simple mathematical measures as a combination of correlation loss, luminance distortion, and contrast distortion.

In the first experiment, we take Lena, Peppers, Baboon and Bridge of 256×256 with quality factor 30, 50, 70, 90 respectively as cover images, and compare the universal quality index of our method and F5 under the same quality factor and the same bits of hidden messages. In Fig. 3, it shows that our method always has higher Q values than F5, which means a better visual quality.



(a)

(b)

(c)

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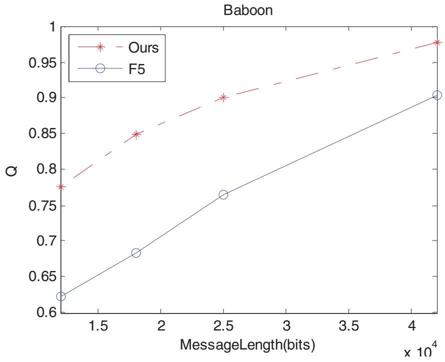

(d)

Figure 3. Performance between our method and F5 at Q with quality factor 30, 50, 70, 90 respectively. (a) Lena. (b) Peppers. (c) Baboon. (d) Bridge.

In the second experiment, we test the cover image "baboon" with quality factor 80 for different relative payload *α* ranging from 0 to 15. We use the embedding efficiency *e* to show the performance of the different payload *α*. For applications in steganography, payload-embedding efficiency is generally equivalent to the rate-distortion measurement.

$$e = m / D(x, y), \tag{7}$$

where the total embedding impact $D(x, y)$ has been discussed in section 2, *m* is the length of message bits.

As is shown in Fig. 4, the proposed scheme achieves a good payload-embedding efficiency performance, and has a great advantage over F5.

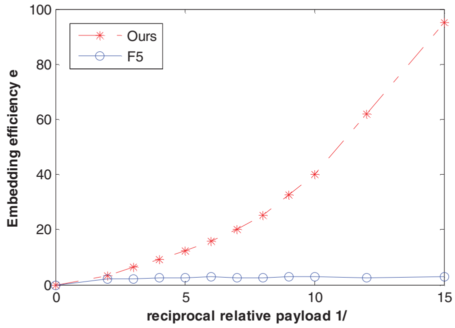

Figure 4. Embedding efficiency of our method and F5 at different payload

IV. CONCLUSION

The proposed method achieves a good rate-embedding efficiency performance as well as guarantees the high visual quality. Introduction of the Watson's work, we build a HVS embedding distortion model which assigns an imbedding cost for each DCT coefficient of the cover elements. The syndrome-trellis codes help to minimize the total imbedding impact. Our experimental results indicate that it outperforms the F5 significantly in visual quality and statistic characteristics under different types of images and different payload. The problem to embed a given payload with minimal embedding impact always drew data hider's attention. In the future, we plan to study the dynamic distortion model during the embedding processing.

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