A High-Payload Image Hiding Method Using Two-Way Block Matching

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ABSTRACT

This paper presents a novel image hiding method that utilizes a two-way block-matching procedure to search for the highest-similarity block for each block of the important image. The bases and indexes obtained together with some not-well-matched blocks are recorded in the least significant bits of the cover image using a hop scheme. The method exhibits a high data payload, which reduces the storage and transmission-time requirements, and also provides a method that prevents an observer from selectively blocking the transmission of the important image.

Index Terms: Image hiding, information hiding, hiding.

I. INTRODUCTION

Hiding is the art and science of concealed communication. The basic idea is to embed important data in a standard cover object (as a text, image, video, or audio segment) to form the stego-data. The stego-data is stored and transmitted to the receiver in the same way as the cover object. To unintended observers, the stego-data exhibits the content of the cover object. However, from the designated receiver's viewpoint, the stego-data carries important data under the camouflage of the cover object that can be revealed using the corresponding extraction algorithm. Unlike encryption techniques in which the important data are protected by the unreadability of the ciphertext, the main idea of hiding is to conceal the very existence of the important data. The advantages of using a method that conceals the important data is that it also prevents an observer from selectively blocking the transmission of such data. Moreover, in contrast to a watermarking system in which the embedded data tends to be related to the cover object, the information carried in the stego-data tends to be independent of the cover object – one crucial principle in designing a hiding algorithm is maintaining the imperceptibility of the important data.

Many image hiding methods for hiding data in still images have been proposed [1–3]. In order to maintain the secrecy of important data in an image, only a small amount of data can be encoded therein (called the data payload). To obtain higher payloads, image-hiding methods based on least-significant-bit (LSB) substitution have been proposed [4–6]. These methods typically utilize some mapping rules to embed the important image in certain LSB planes of the cover image, and apply additional pixel-adjustment procedures to reduce the errors introduced in the embedding process. Meanwhile, some studies [7,8] have considered the characteristics of the human vision system when evaluating the number of bits that can be hidden in an image. Given that human eyes are most sensitive to edges, these methods usually hide more data in areas with higher spatial variations.

The data payload and the imperceptibility are the two most important properties of a hiding system. Intrinsically these requirements contradict each other, since a high data payload introduces more artifacts into the cover image, and hence increases the perceptibility of the hidden data. Previous attempts [2,7,8] to maintain both the imperceptibility and a high data payload have worked from the imperceptibility metric: estimating the degree of alterations that are imperceptible to viewers, and then embedding data within this constraint. In

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military and commercial applications, a large amount of communication by a site tends to expose its position and value. Moreover, due to physical constraints and security concerns, the bandwidth of a communication channel where stego-images are used tends to be low.

In this paper, we develop an image hiding method from the viewpoint of first considering the payload parameter. The proposed method applies a block-matching procedure to search for the highest-similarity block from a series of numbered candidate blocks generated from the cover image, and embeds the indexing information in imperceptible areas of the cover image. Owing to the resulting smaller size of the stego-image, this method makes the important image more secure.

II. STEGANOGRAPHIC SCHEME

A two-way block-matching scheme is proposed to embed a relatively large important image into a relatively small cover image. In the proposed method, the entire important image is first divided into multiple image blocks, and each block is represented using two base-difference forms: an {odd_base + odd_difference} form and a {even_base + even_difference} form. For each block, we search for the odd difference block with the highest similarity from a set of numbered odd candidate blocks, and for the even difference block with the highest similarity from a set of numbered even candidate blocks. The best-matching block is defined as the highest-similarity odd difference block if the distance between the odd_difference and its corresponding highest-similarity odd difference block is smaller than the distance between the even_difference and its corresponding highest-similarity even difference block, and as the highest-similarity even difference block otherwise. Finally, the odd_base (or even_base) and its best-matching index of each important block are recorded in the LSB planes of the cover image using a hop embedding scheme. The proposed method is detailed below.

Consider an important image IM of size $h_{\mathrm{IM}} \times w_{\mathrm{IM}}$, and a cover image CO of size $h_{\mathrm{CO}} \times w_{\mathrm{CO}}$, where both CO and IM are *k*-bit images. Our aim is to embed IM in the *q* (2 or 3) LSB planes of CO. We divide the important image into multiple nonoverlapping blocks of size $m \times n$. Without loss of generality, for the *r*-th block $B_r = \{b_{11}, b_{12}, ..., b_{mn}\}$ with block mean $\overline{\mu}_r$, the odd/even base OB_r / EB_r of B_r is defined to be the corresponding odd/even integer closest to $\overline{\mu}_r$, respectively. B_r can be represented using a base-difference form:

$$B_r = \begin{cases} OB_r + ODIFF_r, & \text{or} \\ EB_r + EDIFF_r, \end{cases} \quad (1)$$

Where

$$\begin{cases} ODIFF_r = \{odiff_{ij}\} = \{b_{ij} - OB_r\}, \\ 1 \le i \le m, 1 \le j \le n, \\ EDIFF_r = \{ediff_{ij}\} = \{b_{ij} - EB_r\}, \\ 1 \le i \le m, 1 \le j \le n. \end{cases} \quad (2)$$

In the base-difference form, we search for the index $oind_r$ of the highest-similarity block of $ODIFF_r$ by comparing it with $2^t - 1$ odd candidate blocks $\{OCand_1, OCand_2, \ldots, OCand_{2^t-1}\}$. Similarly, the index $eind_r$ of the highest-similarity block of $EDIFF_r$ is evaluated by comparing it with $2^t - 1$ even candidate blocks $\{ECand_1, ECand_2, \ldots, ECand_{2^t-1}\}$:

$$\begin{cases} oind_r = \arg\min_j \{Dist(ODIFF_r, OCand_j)\}, \\ 0 \le j < 2^t - 1, \\ eind_r = \arg\min_j \{Dist(EDIFF_r, ECand_j)\}, \\ 0 \le j < 2^t - 1. \end{cases} \quad (3)$$

The distance measure between two blocks in this paper is

$$Dist(P, S) = \frac{1}{m \times n} \sum_{1 \le i \le m, 1 \le j \le n} (p_{ij} - s_{ij})^2, \quad (4)$$

where p_{ij} and s_{ij} are pixels in blocks *P* and *S*, respectively. The best base-difference representation of B_r is then evaluated using

$$B_r = \begin{cases} OB_r + OCand_{oind_r} \\ \text{if } Dist(OB_r + OCand_{oind_r}, B_r) < \\ Dist(EB_r + ECand_{eind_r}, B_r), \\ EB_r + ECand_{eind_r} \quad \text{otherwise.} \end{cases} \quad (5)$$

The following procedure is applied to generate the $2^t - 1$ odd/even candidate blocks. A candidate image CAND is generated by replacing the *q* LSB planes of CO with its (*q*+1)-to-2*q* LSB planes. We repeatedly take an $m \times n$ block, say $D = \{d_{11}, d_{12}, ..., d_{mn}\}$ with block mean $\bar{\mu}_D$, from CAND sequentially, and generate two difference blocks $PD(D) = \{pd_{ij}\}$ and $ND(D) = \{nd_{ij}\}$ from D using

$$pd_{ij} = d_{ij} - \bar{\mu}_D, 1 \le i \le m, 1 \le j \le n, \quad (6)$$

$$nd_{ij} = \bar{\mu}_D - d_{ij}, 1 \le i \le m, 1 \le j \le n. \quad (7)$$

If the distances between the current generated $PD(D)/ND(D)$ and z (a user-defined threshold) previous built odd/even candidate blocks are all greater than a threshold φ, the current generated $PD(D)/ND(D)$ is assigned to be a new odd/even candidate block. The above process repeats until $2^t - 1$ odd/even candidate blocks are generated. Note that if the current scan on CAND is insufficient to generate the desired $2^t - 1$ odd/even candidate blocks, the pixels of CAND are circular shifted right/down one pixel, and the shifted CAND is scanned to continue the generation of the odd/even candidate blocks.

The block-matching method described above determines the most-similar block for each important image block, but the error between an important image block and its best-matching block may still be sufficiently large to cause serious degradation to the important image. To reduce the degradation, some not-well-matched blocks are embedded directly in the cover image. Since the total storage of the q LSB planes of CO is $q \times h_{\text{CO}} \times w_{\text{CO}}$ bits, and the block bases and indexes occupy $(k+t) \times (h_{\text{IM}} \times w_{\text{IM}})/(m \times n)$ bits, the remaining space in the q LSB planes that can be used to hold those not-well-matched blocks is $q \times h_{\text{CO}} \times w_{\text{CO}} - (k+t) \times (h_{\text{IM}} \times w_{\text{IM}})/(m \times n)$ bits. Each block occupies $m \times n \times k$ bits, and hence the number of not-well-matched blocks that can be embedded is

$$\delta = \frac{q \times h_{\text{CO}} \times w_{\text{CO}} - (k+t) \times (h_{\text{IM}} \times w_{\text{IM}})/(m \times n)}{m \times n \times k}. \quad (8)$$

After determining the number of not-well-matched blocks that should be embedded in the cover image, the δ important image blocks with the largest errors between them and their respective best-matching blocks are embedded directly in CO with their best-matching indexes set to $2^t - 1$. To reduce the amount of data to be hidden in CO, the bases, indexes, and δ not-well-matched blocks are encoded using a Huffman coding scheme. Finally, we embed parameters h_{IM}, w_{IM}, k, q, t, z, m, n, and φ, the Huffman table, and the Huffman coding output stream in the q LSBs of CO using the following three-pass-hop embedding scheme in order to scatter the data over the LSBs and further increase the security of the embedded data.

The three-pass-hop embedding scheme uses a pseudorandom number sequence $r_1, r_2, \ldots, r_{h_{\text{CO}} \times w_{\text{CO}}}$, $0 \le r_i < q$ for $i = 1, 2, ..., h_{\text{CO}} \times w_{\text{CO}}$, in the embedding process. The pixels of the cover image is scanned from left to right, and from top to bottom in each pass. In the first pass, we sequentially take $r_i, i = 1, 2, ..., h_{\text{CO}} \times w_{\text{CO}}$, bits of the important data and embed them in the r_i ($0, 1, ..., r_{i-1}$) LSBs of the i-th pixel of the cover image. In the second pass, if $r_i \bmod 2 = 1$, $q - r_i$ bits of important data are fetched and embedded in the $q - r_i$ ($r_i, r_{i+1}, ..., [q-1]$) not-yet-embedded LSBs of the i-th pixel of the cover image; otherwise, the pixel is skipped. If there are still important data to be embedded at the end of the second pass, the remaining bits are sequentially embedded in these unused q LSBs of the cover image by a third pass.

The following steps are applied to extract the important image from the stego-image:

1. Extract parameters h_{IM}, w_{IM}, k, q, t, z, m, n, and φ, and the Huffman table, and apply the inverse hop scheme to extract the Huffman codes from the LSBs of the stego-image.
2. Decode the Huffman codes to obtain the block bases and indexes, and not-well-matched blocks.
3. Applying the candidate-block-generating procedure presented in the embedding process to generate $2^t - 1$ odd candidate blocks and $2^t - 1$ even candidate blocks from the stego-image instead of the cover image.
4. Repeat taking the next sequential index, say ind_i, that is not yet processed, and execute the following substeps until the entire important image is extracted:
   - 3a. If $ind_i \ne 2^t - 1$ and the corresponding base $base_{ind_i}$ is odd, add the ind_i-th odd candidate block to $base_{ind_i}$ and assign it to a new block of the important image.
   - 3b. If $ind_i \ne 2^t - 1$ and the corresponding base $base_{ind_i}$ is even, add the ind_i-th even candidate block to $base_{ind_i}$ and assign it to a new block of the important

image.

3c. If $ind_i = 2^t - 1$, take the next not-well-matched block and used it as the reconstructed block for the current position of the important image.

Note that in steps 3a and 3b, reconstructed pixels greater than 255 and less than 0 are set to 255 and 0, respectively.

III. EXPERIMENTAL RESULTS

Two experiments were conducted to test the efficacy of the method described in this paper. In the first experiment, we hid an important image in a cover image of the same size using the following parameters: $q = 2$, $t = 16$, z = 3, $\varphi = 32$, and a block size of 4×4. Figure 1 shows an example of this test using the cover image "Lena" (Fig. 1(a)) and the important image "Jet" (Fig. 1(b)), both of which are of size 512×512 pixels. The stego-image and the extracted important image are shown in Fig. 1(c) and 1(d), respectively. The peak signal-to-noise ratio (PSNR) between Fig. 1(a) and 1(c) is 44.22 dB, and between Fig. 1(b) and 1(d) it is 39.36 dB. From Fig. 1(c), we can see that the quality of the stego-image is high, and unintended observers will not be aware of the existence of the hidden important image. Indeed, it is impossible to distinguish between Fig. 1(c) and 1(a) or between Fig. 1(d) and 1(b) using the naked eye, which indicates that the value and normal usage of the important image are preserved. Table 1 summarizes the PSNR values of this experiment. The high values of the PSNR indicate that both the stego-image and the extracted important image are of acceptable quality.

In the second experiment, we attempted to hide an important image that was four times larger than the cover image using the following parameters: $q = 3$, $t = 16$, z = 3, $\varphi = 32$, and a block size of 4×8. Figure 2 shows the results of this experiment, where Fig. 2(a) is the cover image "Lena" of size 512×512 pixels, and Fig. 2(b) is the important image of size 1024×1024 pixels generated by tiling four images together into a single image. The stego-image and the extracted image are shown in Fig. 2(c) and 2(d), respectively. The PSNR between Fig. 2(a) and 2(c) is 37.93 dB, and between Fig. 2(b) and 2(d) it is 32.41 dB. In this high-payload embedding test, we can see that both the stego-image and the extracted image are still of high quality, and would be considered acceptable in many applications.

IV. CONCLUSION

This paper presents a high-payload image hiding method. Carefully design of the two-way block-matching procedure and the hop embedding scheme has resulted in both the stego-image and extracted important image being of high quality. The high hiding capacity enables users to send relatively large secret images in an environment where the size of the cover image is relatively small. For example, photographers who work in enemy areas could use this method to hide spy photographs in incurious landscape photographs, and transfer these stego-photographs in a more secure and efficient way.

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Table 1. The PSNR (A) between the stego-image and cover image and (B) between the extracted important image and original important image, in the first experiment. (unit: dB)

A / B	Embedded					
Cover	House	Jet	Lena	Milk	Scene	Tiff
House		44.31/35.41	44.25/37.06	44.26/40.59	44.15/31.35	44.28/37.93
Jet	44.42/44.42		44.21/39.97	44.22/43.25	44.19/34.80	44.27/40.32
Lena	44.53/44.42	44.26/39.37		44.20/43.21	44.18/34.52	44.28/40.77
Milk	44.42/44.55	44.24/39.57	44.20/39.90		44.18/34.10	44.25/40.38
Scene	44.51/43.16	44.30/38.97	44.23/39.37	44.22/42.27		44.30/40.02
Tiff	44.46/44.36	44.29/38.65	44.23/40.12	44.22/43.20	44.22/33.97	
Mean	44.47/44.18	44.28/38.39	44.23/39.28	44.22/42.50	44.18/33.75	44.28/39.88

(a)

(b)

(b)

(d)

Fig. 1. An example of hiding an important image in a cover image of the same size: (a) cover image, (b) important image, (c) stego-image, (d) extracted important image.

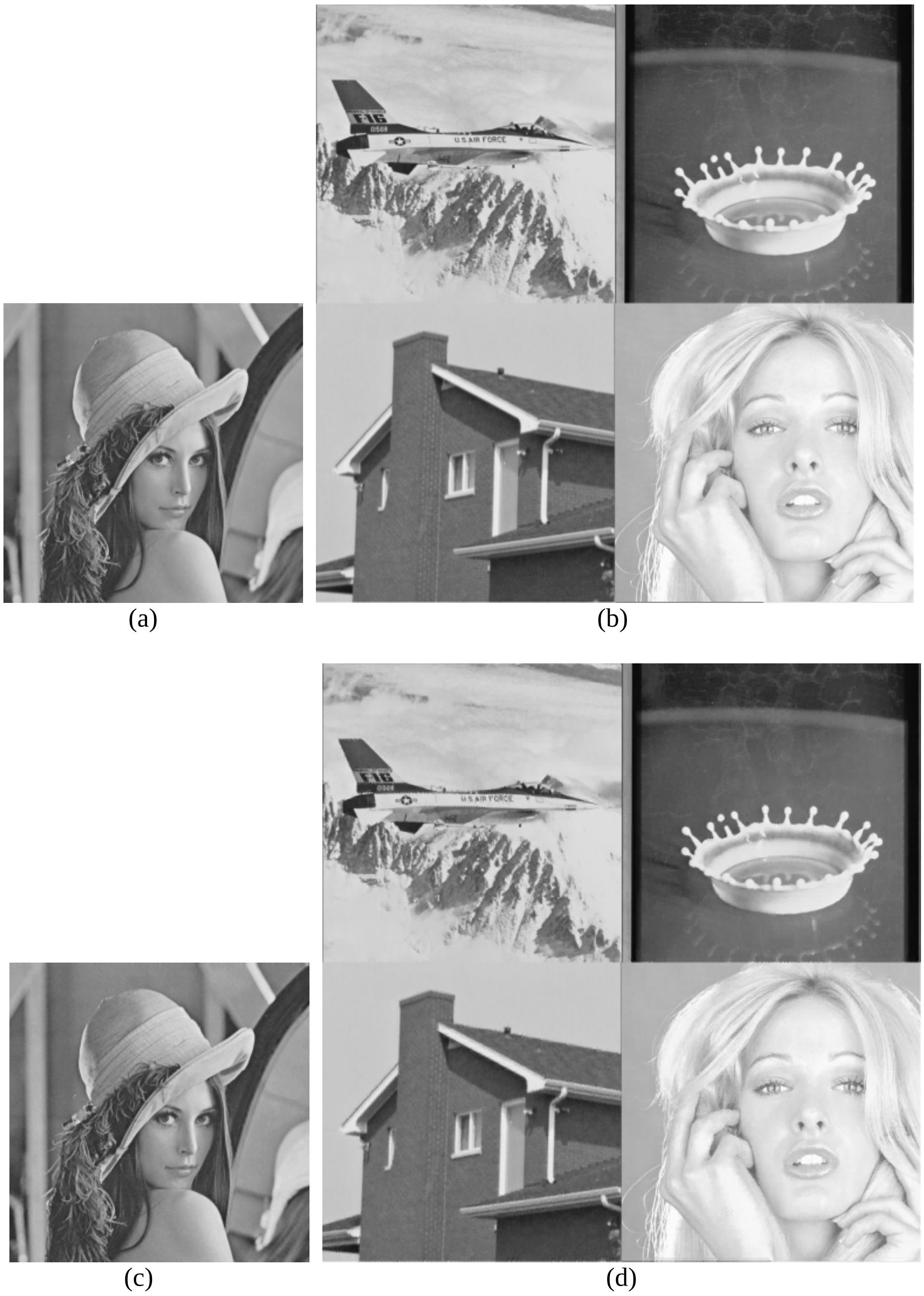

Fig. 2. An example of hiding an important image that is four times larger than the cover image: (a) cover image, (b) important image, (c) stego-image, (d) extracted important image.