



## A High-Capacity Digital Image Data Hiding Scheme Using Adaptive LSB Substitution

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**Abstract**— Many existing steganographic methods hide more secret data into edged areas than smooth areas in the host image, which does not differentiate textures from edges and causes serious degradation in actual edge areas. To avoid abrupt changes in image edge areas, as well as to achieve better quality of the stego-image, a novel image data hiding technique by adaptive Least Significant Bits (LSBs) substitution is proposed in this paper. The scheme exploits the brightness, edges, and texture masking of the host image to estimate the number  $k$  of LSBs for data hiding. Pixels in the noise non-sensitive regions are embedded by a  $k$ -bit LSB substitution with a larger value of  $k$  than that of the pixels in noise sensitive regions. Moreover, an optimal pixel adjustment process is used to enhance stego-image visual quality obtained by simple LSB substitution method. To ensure that the adaptive number  $k$  of LSBs remains unchanged after pixel modification, the LSBs number is computed by the high-order bits rather than all the bits of the image pixel value. The theoretical analyses and experiment results show that the proposed method achieves higher embedding capacity and better stegoimage quality compared with some existing LSB methods

**Keywords**— Data Hiding, Adaptive Least Significant Bits Substitution, Human Visual System, High Embedding Capacity, Optimal Pixel Adjustment Process.

### I. INTRODUCTION

With the development of the Internet and information processing technique, as an effective solution. For copyright protection and information security, data hiding technique has been receiving much attention today. Many data hiding methods have been proposed to hide secret data into an Digital image [1-5]. Data payload (embedding capacity) and imperceptibility are the two most important properties of a data hiding system. Generally, data hiding schemes are categorized as LSB substitution, LSB matching and Pixel-Value Differencing (PVD). LSB substitution is the most commonly used method directly replacing the LSBs of pixels in the cover image with secret bits to get the stego-image [6, 7]. The LSB matching scheme was introduced by A. Ker et al., [8]. LSB matching also modifies the LSBs of the cover image for data hiding, but it does not simply replace the LSBs of the cover image as LSB replacement does. On the other hand, if one secret bit does not match the LSB of the cover image, then another one will be randomly added or subtracted from the cover pixel value [9-11]. PVD method provides good imperceptibility by calculating the difference of two consecutive pixels to determine the depth of the embedded bits [12]. This paper focuses on LSB replacement and PVD methods. The simple LSB scheme is limited mainly by artificial noises in the smooth regions of the image. Artificial noises seriously damage visual quality of the stego-image. To improve the perceptual quality of the stego-image, Wang et al. [13, 14] employed a genetic algorithm to generate a substitution table. According to this substitution table, the value of the secret data to be embedded into each host pixel is transformed to another value in advance which is closer to the original value of the host pixel; however, owing to the nature of a genetic algorithm, although the substitution table is good, it may not be the optimal solution. In order to obtain the optimal solution, Chang et al. [15, 16] proposed their dynamic programming strategy to efficiently pick out the best from all possible substitution tables. But the optimal substitution process may require huge computational cost because of using genetic algorithm and dynamic programming strategy. In Chan et al.'s methods [17, 18], the genetic algorithm is not required. An Optimal Pixel Adjustment Process (OPAP) is used to improve efficiency and enhance the visual quality of the stego-image generated by simple LSB substitution. The above-mentioned LSB techniques [13-18] replace the same length bits of each original pixel with the embedding data. However, not all pixels in the image can tolerate equal amounts of changes without noticeable distortion. Therefore, the stego-image has low quality when equally changing LSBs of all pixels. To solve this issue, some LSB based methods employed Human Visual System (HVS) masking characteristics to embed the secret data into the variable sizes of LSBs of each pixel [19-22].

W. N. Lie et al. [19] created a piecewise mapping function according to the HVS contrast sensitivity to determine the adaptive numbers of LSBs for data hiding. Lee et al. [20] exploited the contrast and luminance property of HVS and achieved a variable-sized LSB insertion. In S. H. Liu et al.'s methods [21], each pixel of the original image is grouped according to its intensity, then the frequency of the original pixel in each group is counted, and a bit plane wise

data hiding method is used to embed the secret message into the original image by the principle of the pixel with high frequency priority. Similarly, Kekre et al. [22] determined the embedded capacity of each pixel by considering the luminance from the highest bits residual image. To further improve the quality of the stego-image, some PVD methods [23, 24] were proposed, and these schemes utilized the HVS sensitivity to intensity variations from Smoothness to high contrast by the selection of the width of the range which the difference value of two neighbour Pixels belong to. Ref. [25, 26] checked more than two neighbourhood pixels to determine the payload of each pixel; however, the embedding capacity of these methods is far less than that of PVD methods. Furthermore, Ref. [27, 28] used the Multi-Pixel Differencing (MPD) to estimate smoothness of each pixel. By combining the LSB insertion and PVD methods, Wu et al. [29] proposed a data hiding scheme with a better image quality by using PVD methods alone. In their approach, two consecutive pixels are embedded by the LSB replacement method if their difference value falls into a lower level; similarly, the PVD method is used if the difference value falls into a higher level. In other words, the secret data is hidden into the smooth areas by LSB substitution and PVD methods in the edge areas. Yang et al. [30] proposed an adaptive LSB steganographic method using PVD and LSB replacement. In their scheme, the difference value of two consecutive pixels is used to estimate the hiding capacity into the two pixels. Pixels located in the edge areas are embedded by a  $k$ -bit LSB substitution method with a greater value of  $k$  than that of the pixels located in smooth areas. The scheme embeds more secret data into edged areas than smooth areas in the host image.

From the above analysis, we can see that: (1) some simple LSB approaches equally change the LSBs of all pixels and have poor visual quality of the stego-image [13- 18]; (2) Some improved LSB schemes [19-22] do not fully exploit the HVS masking characteristics, especially the edge masking effect, and they cannot obtain good imperceptibility; (3) Still other PVD related hiding methods follow the principle that the edge areas can tolerate more changes than smooth areas [23-30]. However, this principle obeyed by some existing data hiding schemes does not discriminate texture features from edge ones; the edge areas used by these schemes [23-30] contain both edges and textures. We know edges and sharp details are the most important structural information of an image, and human eyes are more sensitive to edges than textures [31, 32]. We should avoid abrupt changes in the image edge areas during the data embedding procedure [33]. In this paper,

a novel adaptive image steganographic method is proposed. The proposed scheme obeys the principle that edge areas cannot endure abrupt changes, and can embed a large number of secret data while achieving high quality of the stegoimage. The rest of this paper is organized as follows. The human visual masking model is described in Section 2. The proposed method is presented in Section 3. Experiments are shown in Section 4, and analyses and discussions are given in Section 5. Conclusions are drawn in Section 6.

## II. HUMAN VISUAL MASKING MODEL IN SPATIAL DOMAIN FOR DATA HIDING

Designing image adaptive steganographic schemes with human visual perception can obtain higher capacity and lower distortion. In this approach, we exploit the luminance masking, texture masking and edge masking features of the high order image generated by extracting high order bits of the original image and create a spatial HVS masking model in a better way, and then use the visual masking model to develop an adaptive data hiding scheme.

Human eyes usually have different sensitivity to different luminance. In fact, human eyes are more sensitive to changes in the areas with middle level luminance, while less sensitive to changes in those areas with high and low gray-scale values. So, the luminance masking of each pixel can be estimated as

$$\alpha(i, j) = \frac{|x(i, j) - 128|}{128}$$

Where  $x(i, j)$  is the pixel value at the spatial position  $(i, j)$  of the host image  $I$ .

Moreover, distortions are much less visible in highly textured regions than in smooth areas. The smooth regions possess smaller entropy value, while the textured areas possess greater entropy value. Hence, we can depict the texture masking by using the entropy value of the sliding window (All the calculations are based on the image block of size  $(2l + 1) \times (2l + 1)$ , where  $(1 \leq l \leq 4)$ . Greater entropy value corresponds to the texture or edge regions, while smaller entropy value corresponds to the flat areas. Let  $H(i, j)$  be the entropy value of sub-block centred by the pixel at the position  $(i, j)$ , and the entropy  $H(l, j)$  can be used to depict approximately the texture characteristics of the pixel at the position  $(i, j)$ . This maximum entropy is achievable when all of the gray-levels have the same probability. In other words, an image block receives its maximum entropy when it contains the same number of all of the gray-scale values in that block. For a 256-level image block with size  $(2l + 1) \times (2l + 1)$ , the maximum entropy value  $H_{\max}$  is computed by

$$H_{\max} = -\sum_{i=-l}^l \sum_{j=-l}^l \frac{1}{(2l+1)^2} \log_2 \left( \frac{1}{(2l+1)^2} \right) = 2 \log_2(2l+1). \quad (2)$$

Using  $H_{\max}$  as the normalization factor, the normalized entropy  $\beta(i, j)$  of each pixel can be obtained by the formula

$$\beta(i, j) = \frac{H(i, j)}{H_{\max}}$$

Image areas with prominent edges have greater variance value, while smooth image areas have smaller variance value. Let  $V(i, j)$  be the variance (mean square error) of the image block centred by the pixel  $I(i, j)$ . Therefore, we can use the variance  $V(i, j)$  of the image blocks to indicate the edge feature. In addition, we know that the maximum variance is in the block where adjacent pixels have the maximum and minimum permissible grayscale value. The maximum variance  $V_{max}$  is given by

$$V_{max} = \frac{(2l^2 + 2l)(2l^2 + 2l + 1)}{(2l + 1)^4} G^2 < \left( \frac{(2l^2 + 2l + \frac{1}{2})}{(2l + 1)^2} G \right)^2 = \left( \frac{G}{2} \right)^2.$$

It is well known that sharp edges play an important role in human spatial vision [34]. To achieve good imperceptibility, a good data hiding scheme should prevent abrupt changes in edge areas. Because of large entropy values corresponding to the texture or edge areas, the texture masking also includes the impact of the edge parts when it is calculated by the entropy. To avoid corrupting the edge easily and causing severe distortion to the original image during data hiding, we must ensure low hiding capacity in the edge areas. Based on all the above considerations, the effect of HVS masking characteristics is expressed by the formula

$$\phi(i, j) = \alpha(i, j) \times \{ \beta(i, j) - \gamma(i, j) \}.$$

Now, we can compute the bit depth  $k'(i, j)$  of each pixel that can be used for data hiding by the following formula

$$k'(i, j) = \text{round} \left\{ (7 - r - 1) \times \frac{\phi(i, j) - \min(\phi)}{\max(\phi) - \min(\phi)} + 1 \right\}.$$

Where  $1 \leq r \leq 6$ ,  $1 \leq k'(i, j) \leq 7 - r$ , and  $r$  represents the highest bits number of each pixel used to calculate the hiding capacity in each pixel. Function  $\text{round}()$ ,  $\text{max}()$  and  $\text{min}()$  return the nearest integer, the maximum and minimum value of an expression respectively.

Finally, in order to ensure that the bit depth  $k'(i, j)$  of each pixel obeys uniform distribution as far as possible, histogram equalization is applied to the bit depth  $k'(i, j)$  to obtain the final number  $k(i, j)$  of LSBs in each pixel for data hiding. Fig. 1 illustrates the relation between the adaptive number  $k(i, j)$  of LSBs and the number  $r$  of highest bits for the calculation of the hiding capacity in each pixel.

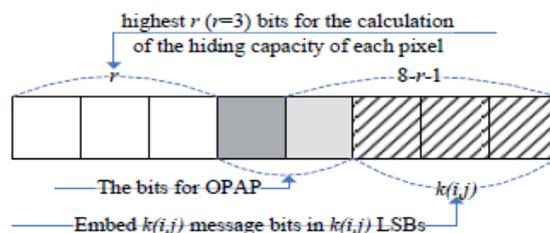


Fig. 1. Relation between the adaptive LSBs number  $k(i, j)$  and the highest bits number  $r$  in each pixel.

### III. PROPOSED STEGANOGRAPHIC SCHEME WITH ADAPTIVE LSB SUBSTITUTION

To obtain high embedding capacity and good invisibility of the stego-image, firstly, we model the HVS masking effect in a better way (see the above section), and then a new image steganographic method is proposed by using the adaptive LSB method and the OPAP presented by Chan [17, 18]. The proposed method is based on the concept that edge areas can tolerate a smaller number of changes than highly textured areas, and not more changes than smooth areas. In fact, the method embeds more secret data into noise non-sensitive areas than noise sensitive areas. Here, the calculation of hiding capacity  $k(i, j)$  of each pixel is based on the highest  $r$  bits of each pixel in the cover image so that the adaptive number  $k(i, j)$  of LSBs of each pixel should remain unchanged before and after data hiding and the adaptation can be achieved with no overhead

#### A. Data Hiding

Let  $I$  be the original 256-level gray scale image of size  $m \times n$  represented as

$$I = \left\{ x(i, j) \mid \begin{array}{l} 0 \leq i < m, 0 \leq j < n, \\ x(i, j) \in \{0, 1, \dots, 255\} \end{array} \right\}.$$

$W$  be the  $t$ -bit secret data represented as

$$W = \{w(i) \mid 0 \leq i < t, w(i) \in \{0, 1\}\}.$$

The detailed data hiding algorithm is given as follows.

Step 1: Extract the highest  $r$  (say  $r=3$ ) bits of the original image  $I$  to get the residual image  $I_r$ .

Step 2: Calculate the adaptive number  $k(i, j)$  of LSBs of each pixel in the original cover-image based on the residual image  $I_r$  using (7).

Step 3: Generate a pseudo random sequence  $P$  with number 0 and 1 by a secret key defined as

$$P = \{p(i) \mid 0 \leq i < t, p(i) \in \{0, 1\}\}.$$

The ultimate secret data  $W^1$  for hiding is obtained by applying the element-wise XOR operation of the original secret messages  $W$  and the pseudo random sequence  $P$  represented as

$$\tilde{W} = \{\tilde{w}(i) \mid \tilde{w}(i) = w(i) \otimes p(i), 0 \leq i < t\}.$$

Where  $\otimes$  denotes XOR operator (the same below).

Step 4: For the  $(i, j)$ th pixel of original image  $I$ ,  $k(i, j)$  bits binary secret data are read from the ultimate secret data  $W^1$  one by one denoted as  $b(i, j)$ , and then transform the binary number  $b$  into its decimal value  $d(i, j)$ . For example, assume  $b(i, j) = 1001_{(2)}$ , then  $d(i, j) = 9$ .

Step 5: Hide  $k(i, j)$  bits binary secret data  $b(i, j)$  into the cover-image  $I$  by replacing the  $k(i, j)$  LSBs of the pixel value  $x(i, j)$  with the integer  $d(i, j)$ , the resulting gray-scale value of the stego-pixel is expressed as

$$x'(i, j) = x(i, j) - x(i, j) \bmod 2^{k(i, j)} + d(i, j).$$

Step 6: To reduce the hiding error between  $x(i, j)$  and  $x'(i, j)$ , the OPAP [17, 18] is used to enhance the quality of stego-image obtained by simple LSB methods. Which bits of each pixel value are used for OPAP is shown in Fig. 1. Let  $\delta(i, j)$  be the hiding error between  $x(i, j)$  and  $x'(i, j)$  which is given by  $\delta(i, j) = x'(i, j) - x(i, j)$ , where  $-2^{k(i, j)} < \delta(i, j) < 2^{k(i, j)}$ . The new gray-scale value  $x''(i, j)$  of the final stego-image  $S$  can be obtained by adjusting the gray-scale value  $x'(i, j)$  with the following formula.

$$x''(i, j) = \begin{cases} x'(i, j) - 2^{k(i, j)}, & \text{if } 2^{k(i, j)-1} < \delta(i, j) < 2^{k(i, j)} \text{ and } \\ & x'(i, j) \bmod 2^{2^s-r} \geq 2^{k(i, j)}; \\ x'(i, j), & \text{if } 2^{k(i, j)-1} < \delta(i, j) < 2^{k(i, j)} \text{ and } \\ & x'(i, j) \bmod 2^{2^s-r} < 2^{k(i, j)}; \\ x'(i, j), & \text{if } -2^{k(i, j)-1} \leq \delta(i, j) \leq 2^{k(i, j)-1}; \\ x'(i, j), & \text{if } -2^{k(i, j)} < \delta(i, j) < -2^{k(i, j)-1} \text{ and } \\ & x'(i, j) \bmod 2^{2^s-r} \geq 2^{2^s-r} - 2^{k(i, j)}; \\ x'(i, j) + 2^{k(i, j)}, & \text{if } -2^{k(i, j)} < \delta(i, j) < -2^{k(i, j)-1} \text{ and } \\ & x'(i, j) \bmod 2^{2^s-r} < 2^{2^s-r} - 2^{k(i, j)}. \end{cases}$$

#### B. Data Extraction

In the data extraction process, given the stego-image  $S$ , the hidden messages can be readily extracted without referring to the original cover-image. The extraction process consists of the following steps.

Step 1: Extract the highest  $r$  (say  $r=3$ ) bits of the final stego-image  $S$  to get the residual image  $S_r$ , note that  $S_r$  is the same as  $I_r$  since data hiding is not applied to the highest  $r$  bits of each pixel.

Step 2: Calculate the adaptive number  $k(i, j)$  of LSBs of each pixel in the stego-image based on the residual image  $S_r$  using (7).

Step 3: Extract  $k(i, j)$  LSBs of the  $(i, j)$ th pixel value  $x''(i, j)$  of stego-image  $S$  directly. Let  $d'(i, j)$  denote the extracted secret data, and it can be defined as

$$d'(i, j) = x''(i, j) \bmod 2^{k(i, j)}.$$

Then the secret message  $b'(i, j)$  is obtained by transforming the decimal value  $d'(i, j)$  to a binary string with  $k(i, j)$  bits

Step 4: Repeat Step 1-3 until all secret data  $W'$  is obtained. Finally, the final secret messages  $W''$  can be obtained by the element-wise XOR operation of the secret data  $W'$  and the pseudo random sequence  $P$  generated by the same method in data hiding, and it can be expressed as

$$W'' = \{w''(i) | w''(i) = w'(i) \otimes p(i), 0 \leq i < t\}.$$

#### IV EXPERIMENTAL RESULTS

In the experiments, some different types of gray scale images with size of 512×512 are used as the cover-images, and four of them are shown in Fig. 2. We set the slide window size in (2)  $l = 1$ . This paper adopts the Peak Signal-to-Noise Ratio (PSNR) to evaluate the qualities of the stegoimages.

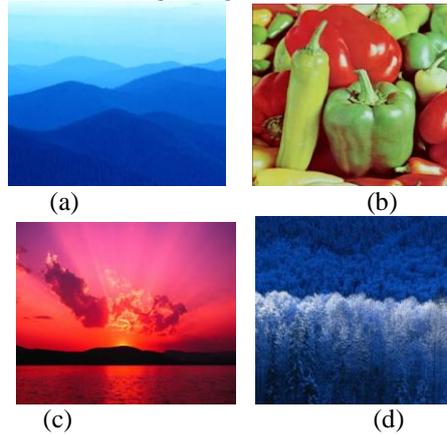


Fig. 2. Four cover images. (a) Blue Hills. (b) Peppers. (c) Sunset. (d) Winter

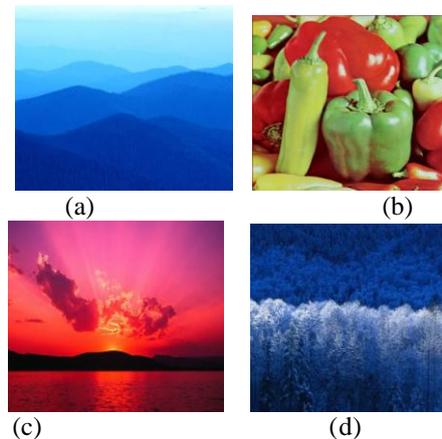


Fig. 3. Four stego-images generated by the proposed scheme.

- (a) Blue Hills (embedded data are 757332 bits, PSNR is 39.3134 dB).
- (b) Peppers (embedded data are 735236 bits, PSNR is 39.5478 dB).
- (c) Sunset (embedded data are 777888 bits, PSNR is 39.1234 dB).
- (d) Winter (embedded data are 786014 bits, PSNR is 39.0636 dB).

To illustrate the imperceptibility of the proposed steganographic method, Fig. 3 shows the corresponding stego-images of four cover images in Fig. 2 obtained by the proposed scheme, where the number of highest bits  $r=4$  is used. Fig. 4 shows the difference between the cover-image and the stego-image by the proposed method, and the gray scale values in the difference images are scaled by 20 times

From Fig. 3, we can notice that there are no perceptible distortions occurring on edge areas by observing the stego-images generated by the presented method. In the experiments, the PSNR values for all the test images processed by the proposed method turned out to be higher than 39 dB with  $r = 4$ , which means the distortion caused by the proposed method is imperceptible to the human eyes. The proposed scheme can achieve good imperceptibility. It is partially because the proposed scheme obeys the concept that the edge areas cannot tolerate great change, and then embeds more secret data into noise non-sensitive areas than noise sensitive areas. In addition, as shown in Fig. 4, the embedding watermark is adaptive to the original image features by observing the difference images. There is low watermark strength in image edge areas. In reality, data hiding has higher capacity in noise non-sensitive regions than noise sensitive ones. Even any visual difference is hardly noticeable on the watermarked image because of the full utilization of HVS masking characteristics. Furthermore, we have also compared the proposed scheme with Wu et al.'s

method [29]. The detailed comparison results are listed in Tab. 1. On average, one can see that the proposed scheme with  $r = 4$  obtains 13049 more bits than Wu et al.'s while the PSNR value increases by 2.14 dB

Cover images	Wu et al.'s method [29]		The proposed method	
	Capacity (bits)	PSNR (dB)	Capacity (bits)	PSNR (dB)
Blue Hills	1851023	84.23	1952155	86.44
Peppers	865156	80.98	886118	83.62
Sunset	1609689	83.76	1715736	86.27
Winter	1816421	79.65	1901567	81.76

Tab. 1. Comparison of results of Wu et al.'s and the proposed methods with  $r=4$ .

## V. ANALYSES AND DISCUSSIONS

In order to further evaluate the performance of the proposed method, we test some different images by using various number of highest bits  $r$  where  $r=1-6$ . The detailed results of four test images “Blue Hills”, “Peppers”, “Sun set” and “Winter” are listed in Tab. 2. The overall performance of the scheme with various  $r$  on different type of images is given in Tab. 3. From Tab. 2, it can be seen that the hiding capacity of each image is different according to the noise sensitivity of the cover image. The higher the noise sensitivity of the cover image, the lower the hiding capacity, which in part indicates the effectiveness of the proposed HVS masking model in Sec. 2. In addition, this approach has relatively steady performance for much different types of images, and the hiding capacity monotonously increases and PSNR value decreases with the highest bits numbers  $r$  for HVS computation, respectively (See Tab. 3).

## VI. CONCLUSION

In this paper, we have proposed a novel steganographic method by using human visual system (HVS) and LSB substitution, which obeys the concept that the edges cannot tolerate great change. The number  $k$  of LSBs for data embedding is adaptive to image pixels by considering the HVS sensitivity to luminance, texture and edge of the host image. The value of  $k$  is calculated by the high-order bits rather than all the bits of the image pixel value, and secret data is embedded into the LSBs not the high-order bits of image pixels, which ensures that the adaptive LSBs number  $k$  remain unchanged after embedding. Extensive experimental results and the theoretical analyses demonstrate the proposed scheme can differentiate textures from edges effectively and avoid abrupt changes in image edge areas. When compared to some existing LSB methods, the proposed method achieves higher embedding capacity and imperceptibility.

In the future, we will exploit the HVS model and difference expansion to develop a lossless watermark scheme with high quality of the stego-image.

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