Optik - International Journal for Light and Electron Optics 213 (2020) 164685

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

High-capacity adaptive steganography based on LSB and Hamming code

Yanting Wang, Mingwei Tang*, Zhen Wang

School of Computer Science and Software Engineering, Xihua University, Chengdu 610039, China

ARTICLE INFO

Keywords:
Edge detection
LSB
Hamming code
Steganography

ABSTRACT

The development of the Internet provides the ability to transfer large amounts of data quickly and easily. However, sensitive data is easily intercepted by hackers on the Internet. Image steganography ensures the secure transmission of information. In order to improve the capacity of hidden secret data and provide imperceptible hidden image quality, this paper proposes a hybrid steganography method based on least significant bit (LSB) replacement and Hamming code (HLAH). Information security is also increased by using two different steganographic methods. Since the sharp areas of the image can tolerate more changes than the smooth areas, more secret messages are embedded in the edge regions of the image and a small amount of information are embedded in the smooth regions. Finally, the performance of the proposed HLAH method is evaluated by measuring payload capacity, mean square error (MSE), peak signal-to-noise ratio (PSNR), and histogram analysis. The experimental results show that the proposed HLAH method not only has greater embedding capacity than other existing methods, but also ensures higher image quality.

1. Introduction

The invention and gradual popularization of the Internet have made it easy to transfer and communicate information. You can learn about the anecdotes and the beauty of the world without leaving your home. However, while the development and progress of the Internet network, the security of information has become a problem that people begin to consider and care about. Countless information are transmitted on the Internet, and anyone's privacy can be sneaked out by others, and the disclosure of personal information and privacy is widespread. In order to solve the security of information, many methods have been proposed in the field of security systems for information encryption and information hiding [1]. Steganography is the technique of hiding secret message in a cover medium in such a way that only the sender and the intended recipient knows the existence of communication.

In recent years, the field of steganography has become the focus of information security. Because every Web site relies on multimedia, such as audio, video and images. Steganography can embed secret information into digital media without affecting its original quality. Third parties are not aware of the existence of secret information or the existence of secret information. Therefore, keys, digital signatures and private information can be securely transmitted on the Internet.

Image steganography techniques can be classified into two categories: spatial domain and frequency domain techniques. In the spatial domain, the secret information is inserted directly in the intensity of the image pixels, while in the latter case, cover images are transformed into the frequency domain, and the secret data is inserted in the transform coefficients. In the spatial domain, the well-known steganography is the least significant bit (LSB) replacement [2–4]. The method embeds secret data by replacing the k-bit

* Corresponding author.

https://doi.org/10.1016/j.ijleo.2020.164685
Received 1 March 2019; Received in revised form 8 January 2020; Accepted 31 March 2020

least significant bit of the pixel with a k-bit secret bit. A Classical Spatial domain technique is Least Significant Bit insertion [5] provide high payload and low computational complexity.

Although the LSB replacement method achieves high embedding capacity, it also has a disadvantage: not all pixels can tolerate the same degree of change, that is, the amount of secret data that can be embedded usually varies from one region to another in a digital image. Therefore, Luo et al. [6] pointed out that the statistical characteristics of the edge regions are more complex than the statistical features of the smooth regions and will be better preserved after data hiding. They proposed a new adaptive steganography that received a lot of attention [7,8].

The adaptive steganography technique [6,9,10] first obtains a statistical global feature of the cover image indicating where the change was made before embedding the LSB or DCT coefficients. It chooses a random adaptive pixel selection that relies on the cover image, and generally avoids areas of uniform color, that is to say smooth areas. Shabir et al. [11] proposed an adaptive high-capacity embedding method based on hybrid edge detector, which uses a hybrid edge detector to detect more edges and achieve high embedding. However, this method needs to use the R channel of the color image to mark the edge information of the two channels G and B, that is, to embed (extra) edge information in addition to the actual embedding, which will undoubtedly reduce the payload of the image and cause distortion of the image. Zinia et al. [12] proposed a new method for concealing data in color images. This method uses LSB algorithm and AES-128 encryption to increase the double-layer security of data, and a new approach of choosing index of image pixel. After the secret message is embedded, the stego-image has good quality compared to the cover image. However, this method only uses the B channel of the color image to hide information, which undoubtedly greatly reduces the capacity of the image. In 2017, Ghosal et al. [13] proposed a high capacity image steganography based on Laplacian of Gaussian (LoG) edge detector. Bai et al. [14] proposed a high capacity steganographic algorithm based on LSB replacement method and edge detection. Bai et al. [14] used the most significant bits (MSBs) of the cover image to obtain edge information, and embedded secret information in the image according to the edge information. In addition, Manashee et al. [15] proposed an adaptive color image steganography method using adjacent pixel value differencing and LSB substitution technique in 2019.

In order to achieve high embedding efficiency, Crandall et al. [16] originally proposed the matrix coding, which effectively reduces the modification when embedding messages into cover images. In 2014, Mao et al. [17] introduced a fast algorithm for matrix embedding steganography to modify the method proposed by Crandall et al. [16]. In addition, Kumar et al. [18] combined with edge detection and coding proposed a steganography algorithm based on local reference edge detection technique and exclusive disjunction (XOR) property.

In this paper, we propose a high-capacity adaptive embedding algorithm based on LSB and Hamming code. In our algorithm, the cover image will be divided into 9×9 non-overlapping blocks. Because studies have shown that the human visual system (HVS) is more sensitive to smooth areas than sharp areas in the image, the proposed method combines edge detection to embed more secret messages at the edge of the image, while a small number of secret messages are embedded in the smooth areas of the image. Moreover, based on the shortcomings of the existing steganographic scheme of edge detection, the proposed scheme avoids the embedding burden of extra edge information and makes full use of the embedding space. The experimental results show that the proposed scheme can achieve high embedding capacity, and also effectively reduce the distortion of stego images and achieve imperceptibility.

The rest of this paper is organized as follows: In Section 2 provides a brief overview of the work. Our proposed method is introduced in Section 3. In Section 4 is the experimental results and analysis to evaluate the steganography method. Section 5 is the conclusion.

2. Related work

In this section, we mainly introduce the method of edge detection and the methods of embedding secret data: LSB and Hamming code.

2.1. Edge detection

Massive literature studies have shown that the human visual system is more sensitive to smooth regions than to sharp regions of the image. Thus, embedding secret information from the sharpest regions into the least sharp regions results in stego images with better visual quality.

There are many methods for edge detection, such as: Roberts, Prewitt, Sobel, Kirsch, Log, Canny, Laplacian, etc. Several classical edge detectors are introduced in [19], and their respective edge detection capabilities are illustrated by experiments. The experimental results show that Canny edge detector is most suitable for a large amount of data hiding. So, in this paper, we are using the Canny edge detector.

2.2. LSB substitution method

The Least Significant Bit (LSB) is the most popular steganography method in the spatial domain, because it is easy to implement and has a high embedding rate. The method embeds secret data by directly replacing the least significant bit of the pixel with a single secret bit.

2.3. Matrix embedding using Hamming code

Richard Hamming invented Hamming code in 1950. It has good performance, high reliability and high transmission efficiency. Therefore, after the discovery of Hamming code soon, it has been widely used. The (n, k) Hamming code is used for matrix embedding, then $n - k$ secret bits can be embedded in n cover bits, and only one bit in the cover vector will change [20].

Mao et al. [17] introduced a fast algorithm for matrix embedding, in which (7,4) Hamming code is used. In this paper, we are using (3,1) Hamming code. Specific steps are as follows:

Step 1: Calculate the generator matrix H of the (3,1) Hamming code. The details are as follows:

The H matrix of the (n, k) linear block code is an $(n - k) \times n = r \times n$ order matrix, where $r = n - k$ is the number of check elements. Obviously, the r check elements can form an r-weight vector in which the 2^r columns are different from each other, and the non-all zero vectors have $2^r - 1$.

From the above, we know that $n = 2^r - 1 = 3$, and $k = 2^r - 1 - r = 1$, from which we can get $r = 2$.

When $r = 2$, there are 3 non-all zeros double vectors: (0 1), (1 0), (1 1).

So, form a matrix

$$H = \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \end{pmatrix}$$

Step 2: Calculate $a = m - Hx$ and convert it to decimal. Where m is the secret bits vector to be embedded and x is the vector of the 2nd significant bit value of the edge pixel of the cover image.

Step 3: Change the value of the ath bit in the vector x. If the value of the ath bit in the vector x is 1, it is changed to 0; otherwise, it is changed to 1.

When extracting, we can directly get the secret message embedded in the cover image by using the following formula.

$$m = \mathrm{H}x' \tag{1}$$

Let us consider an example to illustrate how to embed and extract secret message. Assuming $m = [1\,0]$, $x = [0\,1\,1]$; then, $a = m - Hx = [1\,1]$. Since [1 1] is 3 in the decimal form, the 3th in x should be changed. Therefore, the stego vector is $x = [0\,1\,0]$. On the receiving side, $m = [1\,0]$ is obtained from the formula (1), which is the embedded secret message.

3. The proposed HLAH method

The embedding strategy of our adaptive steganography algorithm is based on the concept that the edge region can tolerate more changes than the smooth region [21]. In order to ensure the payload and quality of the image, in this paper, we use the last two bits of the edge pixel and only one bit in the smooth region of the image to embed secret message. Next, we will introduce the specific details of the proposed solution, including the embedding and extraction of information two processes.

3.1. Embedding process

In this paper, the sizes of color images are 512 × 512, 512 × 384 or 384 × 512. Because the human visual system is less sensitive to changes in the edge regions of the image, we adaptively embed secret messages based on the edge features of the image. The edge detector we use is the Canny operator. In [11], additional edge information needs to be embedded after edge detection, which greatly reduces the payload of image. To address this problem, we will extract the R channel of the color image and clear the last bit of its pixel to zero before performing edge detection. Then, we embed 1-bit secret message in the R channel. If it is an edge region, it is embedded in the G and B channels with LSB and Hamming code. Otherwise, only the LSB method is used to embed the secret information. In order to facilitate the embedding of the Hamming code, we divide the original image into blocks of size 9 × 9.

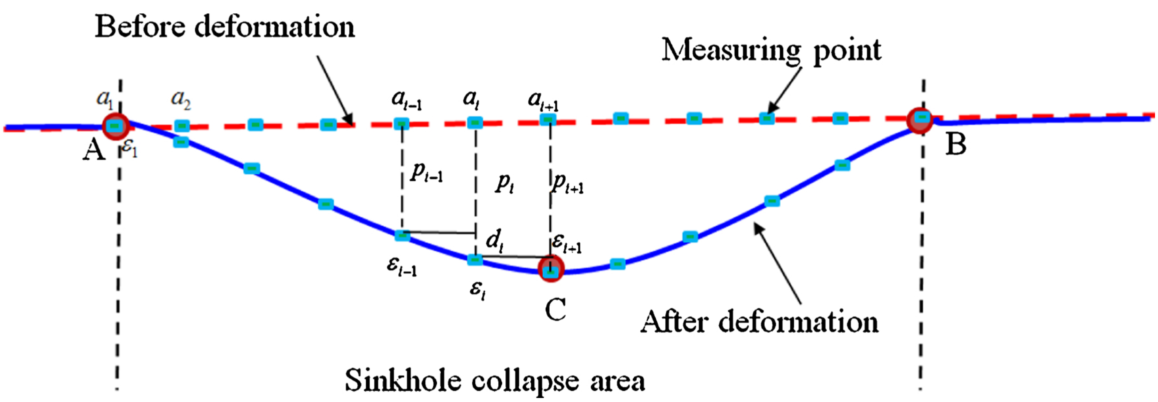


Fig. 1. Embedded flowchart.

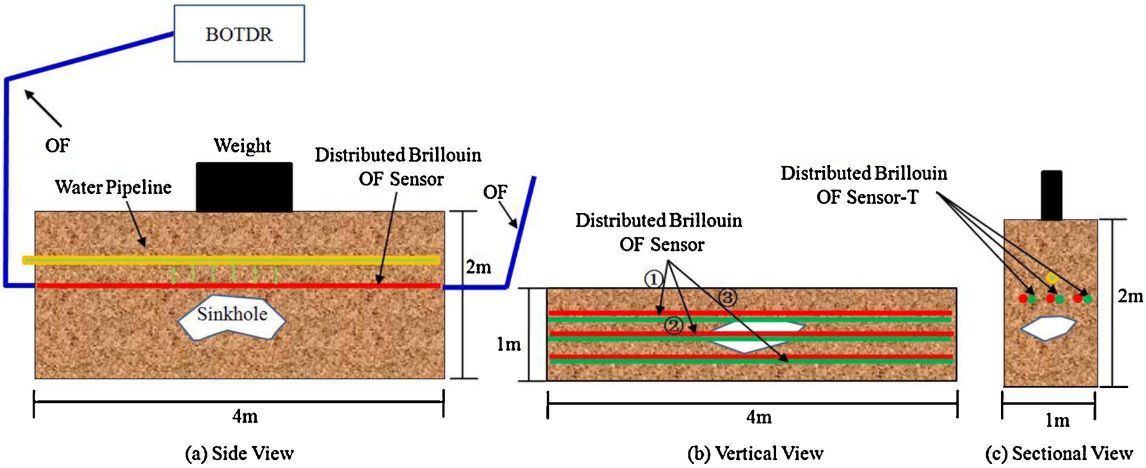


Fig. 2. Example of message embedding process.

Now, we will present a specific flowchart to introduce the embedding process in Fig. 1 and present the embedding algorithm. The specific process of embedding algorithm is as follows:

Step 1: The cover image is divided into blocks of size 9 × 9, and the R channel of the color image is extracted;

Step 2: Clear the least significant bit of the *R* channel to 0, and then perform edge detection.

Step 3: Embedding the secret message according to whether the current pixel $R(i, j)$ is an edge pixel.

(1) If the current pixel $R(i, j)$ is a non-edge pixel, the three channels R, G, and B are embedded by the LSB substitution;

(2) If the current pixel $R(i, j)$ is an edge pixel, the three channels R, G, and B are embedded by the LSB substitution, and the 2-LSB planes of the two channels of G and B are extracted, and then embed information by using (3, 1)) Hamming code.

To facilitate understanding, let us give an example, using LSB and (3,1) Hamming code hybrid method to illustrate the embedded process of secret message, as shown in Fig. 2.

3.2. Extraction process

In this section, we will introduce the extraction process and provide a flowchart. In order to extract the correct secret message, the order of extraction is the same as in the embedding process. We extract the secret message based on whether the pixel value of the secret image is an edge pixel. The extraction flowchart is shown in Fig. 3. The extraction procedure is as follows:

Step 1: Dividing the stego image into blocks of size 9 × 9, and extracting R channels of the stego image;

Step 2: Clear the least significant bits of the *R* channel to 0, and then perform edge detection.

Step 3: Extracting secret messages according to whether the current pixel $R(i, j)$ is an edge pixel.

(1) If the current pixel $R(i, j)$ is a non-edge pixel, extract the last bit of the pixels of R, G, and B channels, respectively;

(2) If the current pixel $R(i, j)$ is an edge pixel, extract the last bit of the pixels of R, G, and B channels, and extract the 2-LSB plane of the channels of G and B, and finally use (3, 1) Hamming code extracts secret messages.

To facilitate understanding, let us give an example, using the LSB and (3,1) Hamming code hybrid method to illustrate the

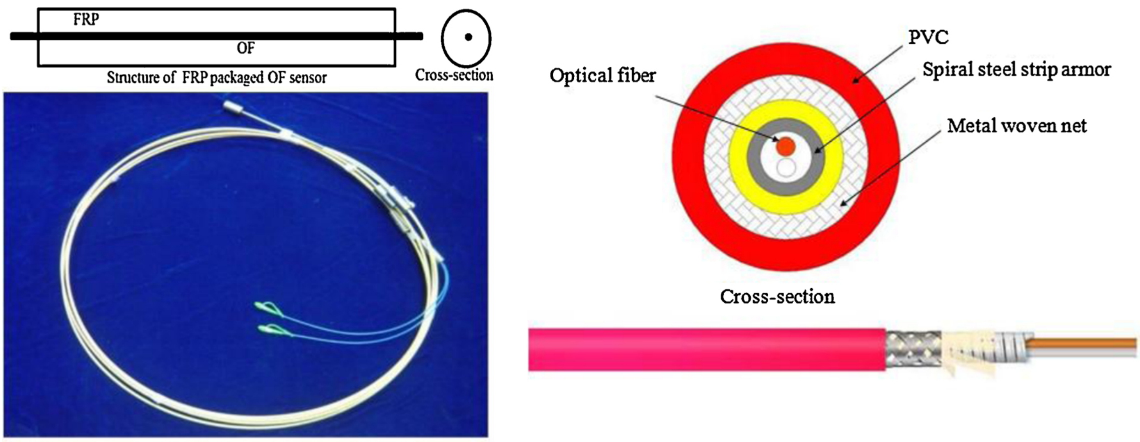


Fig. 3. Extraction flowchart.

Fig. 4. Example of message extraction process.

extraction process of secret information, as shown in Fig. 4.

4. Experimental results and analysis

In this section, we present the experimental results performed to evaluate the performance of proposed method. The results demonstrate the quality assessment of the proposed adaptive steganography technology implemented in MATLAB (R2015b). The experiment was performed on a processor (Intel core i7 3.40 GHz), 8 GB RAM, Window 10, 64-bit operating system. The proposed scheme was compared to the method proposed by Shabir et al. [11], Ghosal et al. [13], Bai et al. [14] and Manashee et al. [15] using color images from the USC-SIPI database (size 512 × 512) and UCID-Image Database (512 × 384 and 384 × 512). In this paper, we only describe the three standard test color images (Lena, Baboon, Airplane) shown in Fig. 5 to determine the performance of the proposed method.

4.1. Perceptual quality assessment

There are two methods for evaluating steganography: capacity and the quality of the image after steganography. The metrics used to evaluate the image quality of the proposed adaptive steganography method are the commonly used mean square error (MSE) and peak signal to noise ratio (PSNR).

4.1.1. Capacity

The payload capacity is a measure of how much of the amount of data can be hidden in the cover image by the proposed steganography. Shabir et al. proposed an adaptive high-capacity embedding method based on hybrid edge detector, which needs to use the R channel of the color image to mark the edge information of the channels of G and B, that is, actually used to embed the secret message only the channels of *G* and *B*. Zinia et al. proposed a new method of hiding data in color images, which only uses the *B* channel of the color image to hide information, greatly reducing the amount of information embedded. In this paper, we embed secret messages in the channels of *R*, *G*, and *B* by using LSB and (3,1) Hamming codes, respectively. Lee et al. [20] proposed an adaptive

Fig. 5. Test image size of 512 × 512.

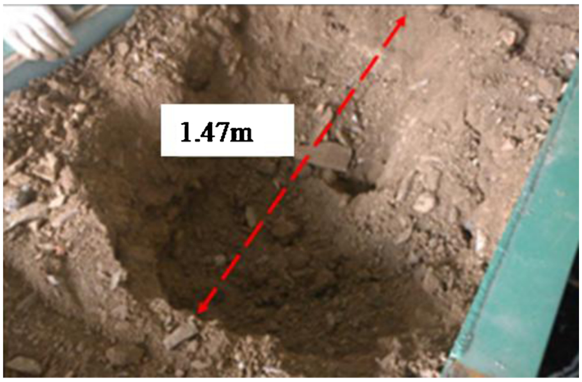


Fig. 6. Test results on all of the 1338 images in UCID-Image Database.

high-fidelity steganography scheme using Hybrid Hamming code. For (n, k) Hamming codes, $(n - k)$ secret bits can be embedded in n cover bits, and only one bit in the cover vector is flipped. Compare with changing the most significant bits, changing the LSBs has less impact on image quality [16]. In this paper, we embed secret messages in the channels of R, G, and B by using LSB and (3,1) Hamming codes, respectively. Compared with Shabir et al. [11], Zinia et al. [12] and Lee et al. [20] to ensure the amount of information embedded.

4.1.2. Mean square error (MSE)

The mean square error is calculated by dividing the sum of the squares of all pixel value differences of the cover image and the stego image by the total number of pixels. The following equation will provide a better understanding. The smaller the MSE value, the better the steganography method.

$$\mathrm{MSE} = \sum_{i=1}^{M} \sum_{j=1}^{N} \frac{(I(i,j) - I'(i,j))^2}{\mathrm{MN}} \tag{2}$$

where i and j are the rows and columns of the image, respectively, so $I(i, j)$ represents the pixel value of the ith row and the jth column of the cover image, and $I'(i, j)$ represents the pixel value of the ith row and the jth column of the stego image.

The proposed HLAH method has been used to all of the 1338 images in UCID-Image Database, which includes many different types of images and the experimental results are illustrated in Fig. 6. As can be clearly seen from Fig. 6, the MSE value of the HLAH method is much lower than the value of the existing methods.

In addition, the experimental results of the average of the MSE values of 50 images of randomly selection from the USC-SIPI database are listed in Fig. 7 for a comparison of the existing methods. The sizes of experimental images are 512 × 512.

4.1.3. Peak Signal to Noise Ratio (PSNR)

PSNR is calculated in decibels. The larger the PSNR value, the better the steganography method. The PSNR is calculated by the following formula:

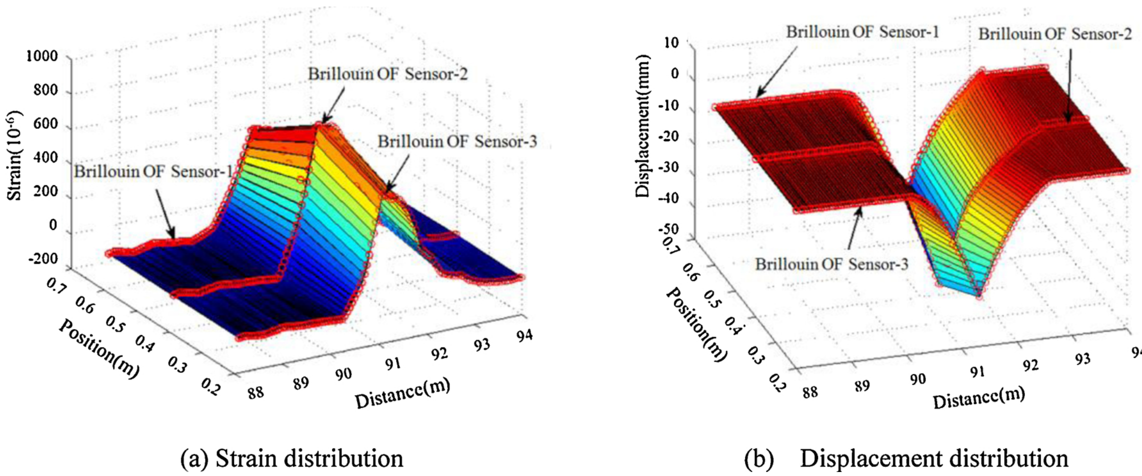
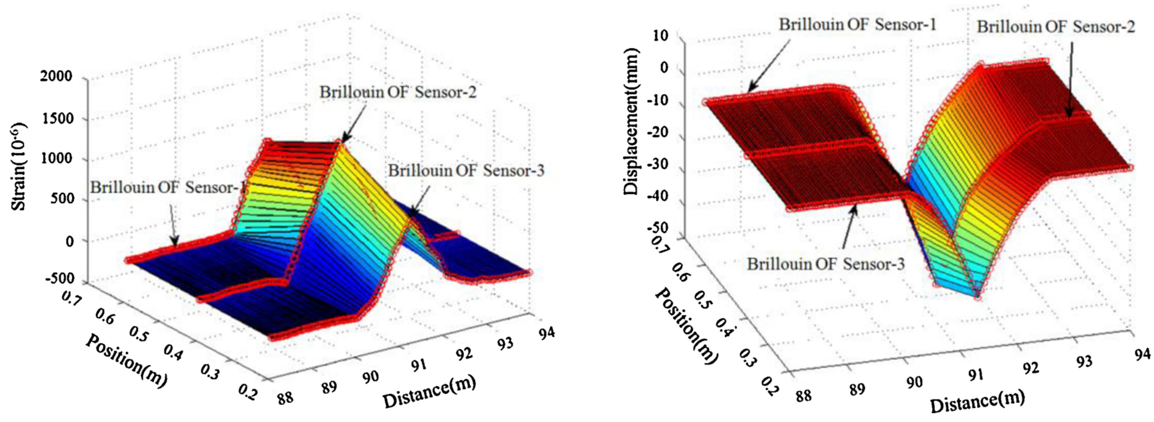


Fig. 7. The average MSE values of the HLAH method compared to the existing methods.



(a) Strain distribution (b) Displacement distribution

Fig. 8. Test results on all of the 1338 images in UCID-Image Database.

$$\mathrm{PSNR} = 10\log_{10}\frac{255^2}{\mathrm{MSE}} \tag{3}$$

The proposed HLAH method has been used to all of the 1338 images in UCID-Image Database, which includes many different types of images and the experimental results are illustrated in Fig. 8. As can be clearly seen from Fig. 8, the PSNR value of the HLAH method is much higher than the value of the existing methods.

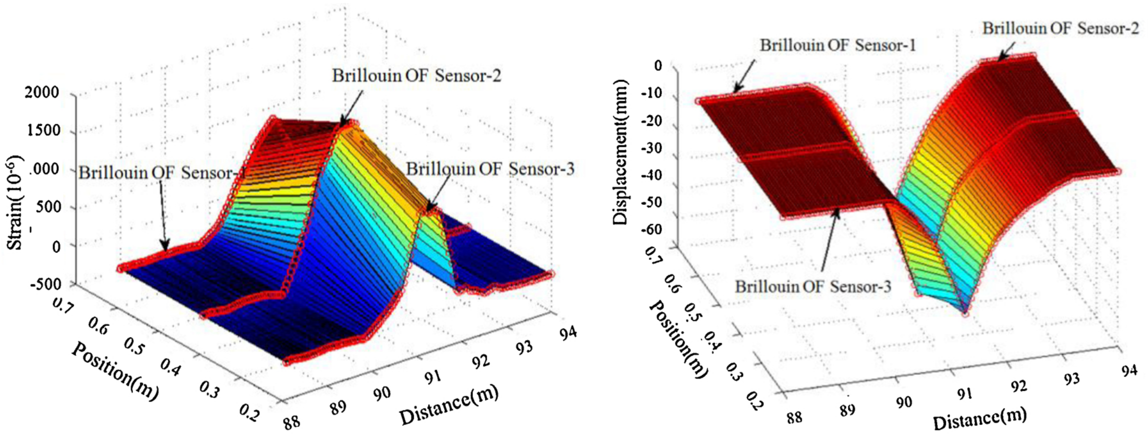
In addition, the experimental results of the average of the PSNR values of 50 images of randomly selection from the USC-SIPI database are listed in Fig. 9 for a comparison of the existing methods. The sizes of experimental images are 512 × 512.

In addition, we also tested the quality of the stego-images of the proposed method and the existing methods under different payloads. Table 1 shows the PSNR values of the proposed method compared to other existing methods.

As is apparent from Table 1, the proposed HLAH method has good image quality compared with other existing methods under the same embedding amount. Even with an embedded capacity of up to 30224Bits, our method's PSNR remains above 60 dB (up to 63.43 dB).

4.2. Histogram analysis

A histogram is a graphical anthropomorphization of the number of occurrences of a pixel. During the embedding of the secret message in the cover image, the pixel values are changed and the histogram is affected. These changes can be used to detect steganography. The small difference between the histogram of the cover image and the stego image makes steganographic detection more difficult. As is apparent from Fig. 10, even with the embedding of the 30224 Bits, there is no significant difference in the histogram of the cover image and the stego image, so the attacker cannot obtain clues about the data embedded in the analysis.



(a) Strain distribution (b) Displacement distribution

Fig. 9. The average PSNR values of the HLAH method compared to the existing methods.

Table 1
The PSNR values of the proposed method compared to other existing methods.

Images	Capacity	the proposed method PSNR	Shabir et al. [11]	Ghosal et al. [13]	Junlan et al. [14]	Manashee et al. [15]
Lena	9424	**68.418**	47.448	61.836	62.770	58.189
	14768	**66.476**	47.442	60.664	60.823	56.256
	16616	**66.008**	47.440	60.264	60.357	55.841
	21368	**64.838**	47.434	59.142	59.232	54.653
	30224	**63.397**	47.424	57.032	57.681	53.196
Baboon	9424	**68.417**	47.433	61.756	62.882	58.262
	14768	**66.523**	47.427	60.412	60.924	56.273
	16616	**66.024**	47.425	60.432	60.357	55.851
	21368	**64.891**	47.419	59.247	59.502	54.662
	30224	**63.430**	47.409	57.473	57.818	53.206
Airplane	9424	**68.429**	47.444	61.852	62.776	58.279
	14768	**66.515**	47.437	60.704	60.801	56.268
	16616	**66.023**	47.435	60.397	60.357	55.863
	21368	**64.949**	47.430	59.243	59.332	54.692
	30224	**63.425**	47.419	57.132	57.697	53.217

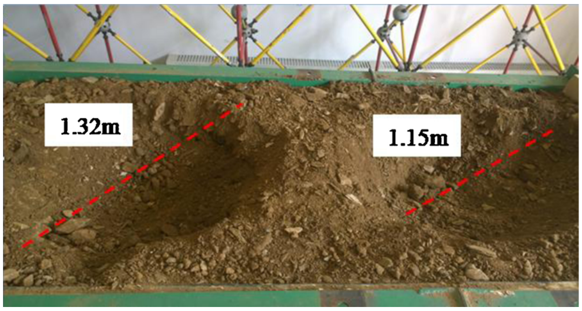


Fig. 10. Histogram of the cover images and the stego images.

5. Conclusion

This paper proposes an adaptive high-capacity steganography method based on LSB and Hamming code (HLAH), which embeds secret data into a color image without producing significant distortion in the cover image. Based on the fact that the human visual system is more sensitive to smooth regions than sharp regions in the image, our proposed method combines edge detection, and then uses LSB and (3,1) Hamming to embed secret messages according to whether the values of piexls are edges. The performance of our proposed method was tested using capacity, MSE, PSNR, and histogram analysis. The experimental results show that our method has great capacity and high image quality.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

This work is supported by “Chun Hui” Research Funds for Educational Department of China under Grant (No. Z2016151), the key of Scientific Research Funds Project of Xihua University (No. Z17133), the Scientific Research Funds Project of Science and Technology Department of Sichuan Province (No. 2016JY0244, 2017JQ0059, 2019GFW131, 2020JY, 2020GFW), Funds Project of Chengdu Science and Technology Bureau (No. 2017-RK00-00026-ZF), the National Natural Science Foundation of China (No. 61902324), the Foundation of Cyberspace Security Key Laboratory of Sichuan Higher Education Institutions (No. sjzz2016-73) and Postgraduate Innovation Fund (No. ycjj2018066).

References

[1] M. Hussain, A.W.A. Wahab, Y.I. Bin Idris, A.T.S. Ho, K.-H. Jung, Image steganography in spatial domain: a survey, Signal Process.-Image Commun. 65 (1) (2018) 46–66, https://doi.org/10.1016/j.image.03.012 ISSN 0923-5965.
[2] C. Thien, J. Lin, A simple and high-hiding capacity method for hiding digit-by-digit data in images based on modulus function, Pattern Recognit. 36 (12) (2003) 2875–2881, https://doi.org/10.1016/S0031-3203(03)0022 ISSN 0031-3203.

[3] C. Chan, L. Cheng, Hiding data in images by simple LSB substitution, Pattern Recognit. 37 (3) (2004) 469–474, https://doi.org/10.1016/j.patcog.2003.08.007 ISSN 0031-3203.
[4] R.Z. Wang, C.F. Lin, J.C. Lin, Image hiding by optimal LSB substitution and genetic algorithm, Pattern Recognit. 34 (3) (2001) 671–683.
[5] N. Akhtar, An LSB Substitution with Bit Inversion Steganography Method, (2016).
[6] W. Luo, F. Huang, J. Huang, Edge adaptive image steganography based on LSB matching revisited, IEEE Trans. Inf. Forensics Secur. 5 (2) (2010) 201–214, https://doi.org/10.1109/TIFS.2010.2041812 ISSN 1556-6013.
[7] S. Tan, B. Li, Targeted steganalysis of edge adaptive image steganography based on LSB matching revisited using B-spline fitting, IEEE Signal Process. Lett. 19 (6) (2012) 336–339, https://doi.org/10.1109/LSP.2012.2194702 ISSN 1070-9908.
[8] X. Li, B. Li, X. Luo, B. Yang, R. Zhu, Steganalysis of a PVD-based content adaptive image steganography, Signal Process. 93 (9) (2013) 2529–2538, https://doi.org/10.1016/j.sigpro.2013.03.029 ISSN 0165-1684.
[9] F. Huang, Y. Zhong, J. Huang, Improved algorithm of edge adaptive image steganography based on LSB matching revisited algorithm, International Workshop on Digital Watermarking (2013).
[10] S. Chakraborty, A.S. Jalal, C. Bhatnagar, LSB based non blind predictive edge adaptive image steganography, Multimed. Tools Appl. 76 (6) (2017) 7973–7987, https://doi.org/10.1007/s11042-016-3449-4 ISSN 1380-7501.
[11] S.A. Parah, J.A. Sheikh, J.A. Akhoon, N.A. Loan, G.M. Bhat, Information hiding in edges: a high capacity information hiding technique using hybrid edge detection, Multimed. Tools Appl. 77 (1) (2018) 185–207, https://doi.org/10.1007/s11042-016-4253-x ISSN 1380-7501.
[12] Z. Sultana, F. Jannat, S.S. Saumik, N. Roy, N.K. Datta, M.N. Islam, A new approach to hide data in color image using LSB steganography technique, International Conference on Electrical Information and Communication Technology (2018).
[13] S.K. Ghosal, J.K. Mandal, R. Sarkar, High payload image steganography based on Laplacian of Gaussian (LoG) edge detector, Multimed. Tools Appl. 77 (23) (2018) 30403–30418, https://doi.org/10.1007/s11042-018-6126-y ISSN 1380-7501.
[14] J. Bai, C.-C. Chang, T.-S. Nguyen, C. Zhu, Y. Liu, A high payload steganographic algorithm based on edge detection, Displays 46 (2017) 42–51, https://doi.org/10.1016/j.displa.2016.12.004 ISSN 0141-9382.
[15] M. Kalita, T. Tuithung, S. Majumder, An adaptive color image steganography method using adjacent pixel value differencing and LSB substitution technique, Cryptologia 43 (5) (2019) 414–437, https://doi.org/10.1080/01611194.2019.1579122.
[16] R. Crandall, Some Notes on Steganography, (1998) http://os.inf.tu-dresden.de/westfeld/crandall.pdf.
[17] Q. Mao, A fast algorithm for matrix embedding steganography, Digit. Signal Process. 25 (2014) 248–254, https://doi.org/10.1016/j.dsp.2013.11.001 ISSN 1051-2004.
[18] K. Gaurav, U. Ghanekar, Image steganography based on Canny edge detection, dilation operator and hybrid coding, J. Inf. Secur. Appl. 41 (2018) 41–51, https://doi.org/10.1016/j.jisa.2018.05.001 ISSN 2214-2126.
[19] G. Shrivakshan, C. Chandrasekar, A Comparison of various edge detection techniques used in image processing, Int. J. Comput. Sci. Issues 9 (2012) 269–276.
[20] C.-F. Lee, C.-C. Chang, X. Xie, K. Mao, R.-H. Shi, An adaptive high-fidelity steganographic scheme using edge detection and hybrid hamming codes, Displays 53 (2018) 30–39:, https://doi.org/10.1016/j.displa.2018.06.001 ISSN 0141-9382.
[21] C.-H. Yang, C.-Y. Weng, S.-J. Wang, H.-M. Sun, Adaptive data hiding in edge areas of images with spatial LSB domain systems, IEEE Trans. Inf. Forensics Secur. 3 (3) (2008) 488–497, https://doi.org/10.1109/TIFS.2008.926097 ISSN 1556-6013.