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StegoBound: A Novel Image Steganography Technique Using Boundary-Based LSB Substitution

Syed Saad Ahmed¹, Mashal Memon¹, Rabeea Jaffari², Moazzam Jawaid¹

¹ Computer Systems Engineering, Mehran University of Engineering and Technology, Jamshoro, Pakistan

² Software Engineering, Mehran University of Engineering and Technology, Jamshoro, Pakistan

Abstract: The safe exchange of private information in the current web age is a significant security concern that has come around after developing steganography as a piece of conspicuous information concealing strategy. Steganography methods guarantee secure information by hiding the transmission channel and are described using three key boundaries: specific strength, implanting limit, and intangibility. The cutting-edge steganography strategies anyway neglect to accomplish an ideal compromise among the key steganographic factors. This research study describes a novel image steganography technique StegoBound based on gradient, which efficiently hides the secret message and produces excellent results for the essential steganographic characteristics. To produce top-notch stego-pictures, StegoBound shrouds the restricted information in the sixth, seventh, and eighth least significant bits (LSBs) of the boundary zone pixels in grayscale cover pictures. The nature of the stego-pictures is assessed through primary closeness file (SSIM), widespread picture quality file (UQI), mean square of error (MSE), Peak Signal to Noise Ratio (PSNR), mean qualities, and histogram investigation. The novel method's effectiveness evaluation is confirmed by calculating MSE, SSIM, PSNR, and UQI. Experimental results and comparative studies reveal that our proposed technique achieves state-of-the-art results in hiding the secret data by providing an optimal trade-off between imperceptibility, embedding capacity, and security.

Keywords: steganography, data hiding, LSB substitution, MSB, boundary.

隐写术界：一种使用基于边界的最低有效位替换的新型图像隐写技术

摘要：在当前的网络时代，隐私信息的安全交换是一个重要的安全问题，它是在将隐写术发展为一种显眼的信息隐藏策略之后出现的。隐写术方法通过隐藏传输通道来保证信息的安全，并使用三个关键边界进行描述：特定强度、植入限制和无形性。无论如何，尖端的隐写术策略都忽略了在关键隐写术因素之间实现理想的折衷。这项研究描述了一种基于梯度的新型图像隐写技术隐写术界，它有效地隐藏了秘密信息，并为基本的隐写特征产生了出色的结果。为了生成一流的隐写图片，隐写术界将受限信息包含在灰度覆盖图片中边界区域像素的第六、第七和第八个最低有效位中。隐写图片的性质通过主要接近度文件、广泛的图片质量文件、误差均方、峰值信噪比、平均质量和直方图调查进行评估。通过计算均方误差、结构相似指数、峰值信噪比和通用图像质量指数来确认新方法的有效性评估。实验结果和比较研究表明，我们提出的技术通过提供不可感知性、嵌入容量和安全性之间的最佳权衡，在隐藏秘密数据方面取得了最先进的结果。

关键词：隐写术、数据隐藏、最低有效位替换、最高有效位、边界。

1. Introduction

Confidential information was once passed down by etching it on the scalps of slaves and servants or hiding it on the backs of wax tablets, rabbits' abdomens, or the backs of wax tablets. With the advent of digitization, automated approaches, such as cryptography and steganography, have replaced the traditional methods and are efficiently used to conceal confidential data. Steganography is a Greek word that signifies "disguised composition." "Steganos" signifies "covered," and "graphy" signifies "composing." The investigation of steganography is the camouflage of information by darkening the transmission or correspondence way [1]. The concealed transmission of hidden data or messages makes steganography different from cryptography. The latter only scrambles the message in an incomprehensible format but does not obfuscate the message's presence, increasing the chance of detection by arousing suspicion. Thus, steganography offers increased benefits over cryptography by concealing the very existence of the message itself, which avoids drawing the interest of unauthenticated users, making it more resilient to the cryptographic approaches [2]. However, for additional security and privacy, steganography and cryptography are often used together [3]. Steganographic techniques are employed in a range of research fields, including but not limited to identifying piracy in digital material, computer forensics, and tracing criminal behavior on the internet. [4].

Steganography works by concealing the private information or the payload inside a transporter (like content, picture, video, or sound); just the sender and beneficiary know about the local intel's quality [5]. The payload message is covered in the transporter/cover medium utilizing a fitting installing capacity to make a stego-transporter vague from the cover medium, keeping away from any doubt. The stego-transporter comprising of the mysterious message is then moved to the beneficiary by the sender. The message is recovered using a removing capacity utilizing a stego-key which is a common mystery between the sender and the beneficiary [6]. The procedure of steganography is depicted in Fig. 1. The most widely used carrier medium for steganography are images where various properties of images such as luminance, contrast, and colors are varied to hide the message [7] and are the main focus of this research study.

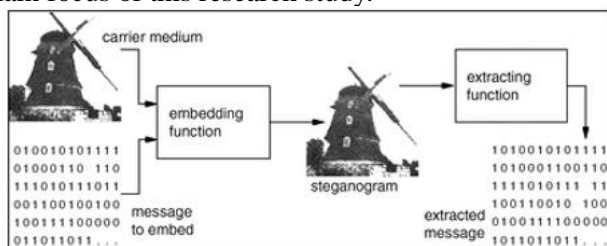


Fig. 1 Steganography process

The success of any steganographic technique can be determined via three parameters, namely: imperceptibility, payload capacity, and robustness. Imperceptibility can be described as the generated stego-image's indistinguishability from the cover image; attackers or stego-analysts find it difficult to uncover the important information in the stego-image. The amount of imperceptibility is commonly expressed in PSNR (Peak Signal to Noise Ratio), with a greater PSNR indicating a higher level of imperceptibility. The amount of message bits that may be securely encoded in the pixels of the cover picture without being statistically detected is referred to as payload capacity. A sufficient payload capacity is required for an efficient steganography process. Finally, resilience assesses the steganographic technique's ability to withstand steganalysis attempts to obtain the secret message. These steganographic parameters have a significant trade-off [5].

Image steganography is partitioned into 2 types: spatial space and transforms/frequency space. After using spatial domain procedures, the important data is straightforwardly concealed in the cover picture. In contrast, transform domain methods are used to hide enormous quantities of data in the frequency space by modifying the amplitude of all transformations of the cover picture. This research study focuses on spatial domain techniques only due to their widespread adoption, high hiding capability, and easy retrieval. However, we refer the readers to the research works in [8], [9], [10] for more information regarding the spatial domain, transforms domain, and steganalysis techniques.

1.1. Motivation

An in-depth survey of the existing literature reveals that although the state-of-the-art spatial domain steganography methods (LSB and MSB) ensure higher imperceptibility, these techniques have poor payload capacity and robustness due to the use of a fixed embedding function and the uniform number of bits, as well as the fixed bit positions (LSB or MSB), to embed the secret message respectively. These shortcomings make it easier for the stego-analysts to intercept and interpret the stego-images. Improvements and modifications to these techniques attempt to improve the payload capacity and robustness (or both) but fail at achieving higher imperceptibility levels. The mentioned shortcomings of the available steganographic methods motivate this research study.

1.2. Contribution

To address the shortcomings in the available steganography approaches, the contributions of this research study are two-fold, namely:

1. A unique picture steganography approach based on boundary-based LSB replacement achieves a good

balance of imperceptibility, payload capacity, and resilience.

2. Validation of the proposed method on benchmark image data using state-of-the-art results.

The following is how the remaining of this research study is ordered: Section 2 discusses the various steganography strategies and their benefits and drawbacks, section 3 discusses the research methodologies used in this work as well as the suggested steganography technology "Stegobound," and section 4 discusses the proposed methodology's experimental validation and results.

2. Related Works

LSB, MSB, and hybrid approaches are the current state-of-the-art spatial domain picture steganography approaches published in the literature. This section provides a quick summary of various strategies.

2.1. Least Significant Bit (LSB) Technique

To make the stego-picture, most of the writing depends on the Most uncritical Bit (LSB) adjustment approach, which embeds the mysterious message at all huge bit of every byte of the cover picture. The mysterious message and the cover picture are changed over to parallel first, and afterward, the mysterious message is embedded in the cover picture's LSBs. This inserting activity is rehashed until each LSB of the cover picture has been utilized. Until the entirety of the mysterious message, bits have been appropriately implanted in the cover picture. [11]. Despite its modest payload capacity and strong imperceptibility, the conventional LSB is subject to simple assaults. As a result, academics have proposed numerous enhancements to the basic LSB approach to enhance the resilience and payload capacity, such as embedding the important data in the LSBs of the brightest and darkest picture pixels [12]. On the other hand, rather than the 1 least significant bit of every byte, the important information may be encoded in the 4 least significant bits of every byte of the cover picture. [13.] Another research suggested by the authors in [14] is to fuse some extra bits with the important message to make the stego-images histogram seem like the first image. In the substitution technique for LSB, this methodology forestalls the histogram attack. The hidden data is embedded in the research described in [15] by utilizing the seventh bit of a picture's chosen pixel as a sign and the seventh bit of the next pixel as a pointer. Two epic steganographic techniques dependent on the substitution of variable length substitution of bits are introduced in [16]. The main methodology hides the least significant bit of personal data per pixel, while the subsequent methodology conceals two bits of important information per pixel utilizing the LSB approach. He et al. utilizes objective examination to compute the implanting profundity with the goal that a versatile number of bits might be disguised in various

pixels to expand the number of bits covered in every pixel [17]. The research work in [18] presents a steganographic framework for RGB pictures to upgrade the payload limit and give great intangibility utilizing sorcery LSB replacement and Hash Message Validation Code (HMAC). Message bit subordinate inserting is proposed by Swain and Lenka in [19], where the important message's touch design help in deciding the substituting positions in the pixels of the cover picture.

LSB steganography procedures are utilized related to various cryptographic and different ways to deal with incrementing the framework's power. [20] gives two cryptographic steganographic approaches; the first proselytes the payload picture into an encoded text utilizing an S-DES cryptographic calculation with a mysterious key and afterward hides the scrambled content into the transporter picture utilizing LSB replacement. The subsequent technique changes over the payload picture into an S-DES scrambled picture and afterward utilizes LSB replacement to conceal it in the transporter picture. The methodology portrayed in [21] consolidates two methodologies, MP (Network Example) and LSB (Bolted Symmetric Paired), in which the mysterious message is covered up inside the framework blocks.

Pixel Value Differencing (PVD) [22], [23] and pixel correlation methods [24], [25] are notable tracks in LSB based substitution where a pixel value calculated from 2 consecutive pixels, which are substituted by the bits of the important data as the new difference in the former technique. In contrast, the pixel correlation scheme exploits the connection of a picture element with its neighboring picture elements for embedding the secret message. A productive and dynamic inserting calculation utilizing the PVD strategy is accounted for in [26] that conceals the secret information and makes secret code-breaking a decent disturbance for the aggressor and addresses an extraction calculation that adequately extricates the whole secret message with no deficiency of secret information.

Lastly, the closest LSB track to our proposed approach is to implant the secret message in the cover picture using edge detection algorithms. Youssef Bassil proposes to implant the important data in the three LSBs of every color channel of the edge pixel determined via Canny's edge algorithm. Still, the research work does not report any results via benchmark steganographic parameters [27]. The research works reported in [28] and [29] embed the secret message in LSBs of edge pixels extracted via edges-identification method and hybrid canny edge detection and a fuzzy edge detector with 2k correction method, respectively. However, our research method utilizes the LSBs of boundary pixels instead of edge pixels to embed the secret message and achieves superior performance in all aspects, as discussed in sections 3 and 4. We refer the readers to survey works

in [30], [31] for more information on LSB steganography techniques.

2.2. Most Significant Bit (MSB) Technique

As the name implies, the MSB technique uses the most or mean significant bits (higher-order bits) for hiding messages in the cover images. Studies have shown that LSB techniques perform better than MSB techniques [32]. However, MSB techniques can offer better security as stego-analysts are usually aware of the LSBs and design the attacks accordingly to extract the secret messages. In this research work, we briefly discuss the MSB techniques in the chronological order of their publication for better comparison and validation of our proposed technique.

[33] utilizes a 1-cycle MSB in a tumultuous way with the mysterious picture key to conceal the secret message. To compute the following looming place in the picture, 8x8 size framework blocks are browsed the cover picture, with the mysterious key in the main square. [34] depicts a reversible information camouflage methodology dependent on Neighbor Mean Interpolation (NMI) and R-weighted coding. Pixel value differencing (PVD) is used in [35] for implanting the data in the RGB image with a variable number of bits for enhanced security. In [36], the embedding of a secret message occurs in the 4th or 5th MSB of the pixel. The pixels to be utilized for embedding are chosen via three-pixel groups, and OPAP (Optimal Pixel Adjustment Process) is used to lessen distortions that are caused due to the embedding procedure. According to the research in [37], the fifth bit of the cover picture is utilized for concealing the mysterious message by utilizing a technique known as touch differencing on the fifth and sixth bits. If the differencing result isn't indistinguishable from the secret message nibbled, the bit of the cover picture is adjusted. In [38], a strategy is proposed. The slightest bit per pixel is hidden in encoded pictures by preprocessing the picture to sidestep mistakes that redo the nature of changed pictures. The research works in [39] and [40] present improved calculations for disguising the important data in MSBs of the RGB cover picture utilizing pixel esteem pointers. In [39], the green channel fills in as a pixel value marker for concealing the mysterious message in the fifth and sixth bits of the blue or red color plane based on even and odd equalities, while in [40] red channel fills in as the pixel value indicator.

2.3. Hybrid Technique

For image steganography, hybrid approaches often combine LSB and MSB methods. Solomon et al. [41] implant the mysterious message in the cover picture utilizing two bits (one LSB and one MSB). [42] depicts a technique for installing a mysterious message in the MSB of a cover picture by utilizing the LSB of the cover picture as a pointer. The research in [43]

recommends a framework where the secret message bits are first encoded utilizing even and odd equalities. Afterward, the important message is implanted in the LSB of the cover picture utilizing the MSBs as the pixel indicator. Though these techniques [42], [43] do not embed the information in the MSB and LSB jointly, they use both the schemes and hence place them under the discussion of hybrid techniques.

2.4. Conclusion

Several spatial domain image steganography techniques were reviewed, such as LSB, MSB, and hybrid techniques. While these techniques have shown acceptable performances, these still do not achieve an optimal trade-off between the key steganographic parameters that are imperceptibility, robustness, and payload capacity [44]. We propose a novel steganography technique in section III, named StegoBound, that resolves this issue and achieves an optimal balance between the steganographic parameters.

3. Stegobound: A Novel Image Steganography Technique Using Boundary-Based LSB Substitution

We propose a new steganography method for implanting the important data in the LSBs of the cover picture's boundary pixels in this research paper. LSB technique is chosen because it guarantees high imperceptibility as compared to the MSB technique. At the same time, the boundary pixels help increase the payload capacity and the robustness of the proposed technique guaranteeing an optimal trade-off between the key parameters.

The novelty of this research is that the data is being hidden in the boundary region, with 3 bits being used to implant the secret information.

StegoBound technique is essentially a two-step process comprising of image segmentation and LSB substitution. Firstly, thresholding-based image segmentation is used to separate the background region of the cover image from its foreground region for boundary calculation. The boundary region is computed via edge detection. The confidential data is then implanted in the cover picture's least significant bits as 6th, 7th, and 8th, using LSB replacement. It should be noted that the proposed method only works with grayscale photos. In sub-sections 2.1 and 2.2, the embedding and extraction methods for implanting and extracting the secret information to/from the cover image are discussed.

3.1. Embedding Algorithm

Input: Grayscale cover image, the secret message

Output: Stego-image

1. Select the secret information and the cover picture.

2. Convert the cover image into binary.
3. Separate the foreground region from the background with thresholding-based segmentation in the cover image.
4. Compute the boundary region in the cover image by edge detection.
5. Embed the secret message in the boundary region pixels (indicated by a high gradient value between the foreground and the background) using three LSBs (6th, 7th, and 8th bit) until the end of the secret message is read to generate the final stego-image.

3.2. Extraction Algorithm

Input: Stego-image

Output: Secret Message

1. Read the stego-image and convert it into binary.
2. Separate foreground region from the background with the help of thresholding-based segmentation.
3. Compute the boundary region in the stego-image by edge detection.
4. Extract the secret message by reading the 6th, 7th, and 8th bits of the stego-image from boundary region pixels (i.e., places where high gradients are observed).

The workflow of the embedding and extraction algorithm is presented in Fig. 2 and 3, respectively.

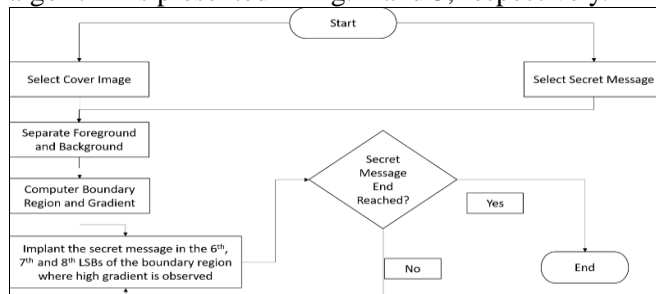


Fig. 2 Workflow of embedding algorithm

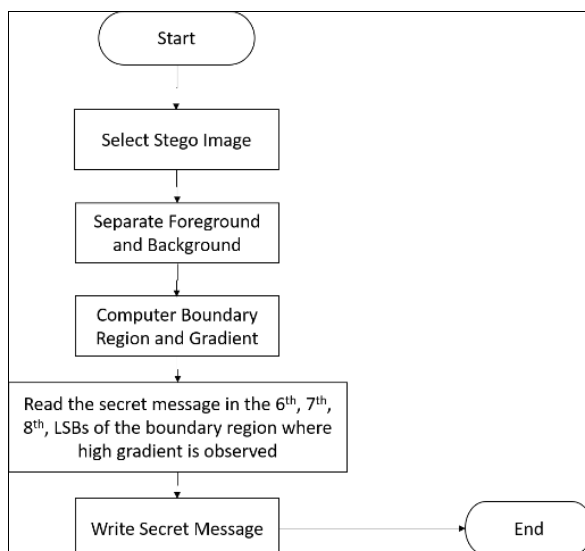


Fig. 3 Workflow of extraction algorithm

4. Results and Discussion

The suggested approach is applied to utilize MATLAB 2017a. Benchmark cover images used to assess the performance of the intended approach are Lena.png, Bluehills.png, Mandrill.png, Boat.png, and House.png, as shown in Fig 4.

The limitation of the results will be if the boundary isn't computed properly, and the foreground and background aren't separated clearly.

The cover images are grayscale png images of size 512x512, 128x256, 512x512, 512x512 and 256x256, respectively.

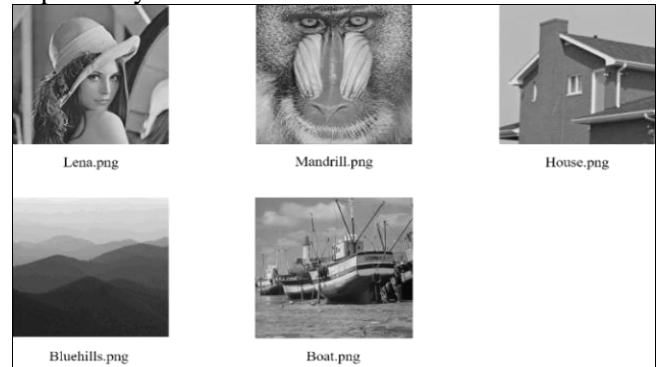


Fig. 4 Benchmark cover images

The stego-images (corresponding to the benchmark cover images) generated via the proposed method StegoBound are depicted in Fig. 5.

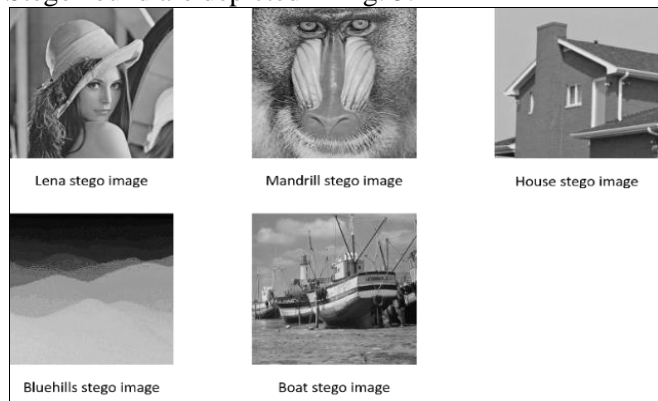


Fig.5 Stego images generated via StegoBound

The generated stego-pictures are entirely identical to the benchmark cover images (shown in Fig. 4) and are unidentifiable by the naked eye, as shown in Fig. 5. That implies that the quality of the images is not altered by implanting the secret message. Moreover, the use of 3 LSBs, i.e., 6th, 7th, and 8th bit for hiding the secret message delivers high payload capacity to this technique, and the use of boundary pixels guarantees better security. The validation findings of the proposed StegoBound methodology are shown and evaluated in terms of imperceptibility, robustness, and payload capacity.

4.1. PSNR and MSE

Imperceptibility of the generated stego-images is evaluated in terms of PSNR values, where a higher PSNR signifies a superior quality stego-image. The

PSNR is, in turn, calculated based on MSE (Mean-squared error) values. The MSE and PSNR values for the stego-images can be mathematically calculated using eq (1) and eq (2), respectively.

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i, j) - K(i, j)]^2 \quad (1)$$

where $m \times n$ denotes the rows and columns of noise-free grayscale stego-image. I and K refer to the original image and the stego picture (processed image). With MSE being calculated, PSNR (in db) is calculated as:

$$PSNR = 20 \cdot \log_{10}(MAX_I) - 10 \cdot \log_{10}(MSE) \quad (2)$$

4.2. Payload Capacity

The payload or the embedding capacity of this steganography method can be determined mathematically using Eq. (3).

$$Payload\ Capacity = \text{Number of boundary pixels} \times 3 \quad (3)$$

The PSNR, MSE, and Capacity values obtained for the stego-images generated via StegoBound (depicted in Fig. 5) are summarized in Table 1.

Table 1 PSNR, MSE, and capacity values for stego-images generated via StegoBound

S.#	Stego Image	PSNR	MSE	Capacity
1	Lena	64.154	0.0125	4755
2	Mandrill	72.439	0.0037	7668
3	House	72.552	0.0036	2856
4	Bluehills	68.047	0.010	2178
5	Boat	64.6688	0.0221	6522

Table 1 shows that the PSNR and MSE values of StegoBound are very good as the PSNR is above 45 decibels (db), and the MSE values are nearly zero. Moreover, the payload capacity of StegoBound is also sufficiently good due to the use of 3 LSBs.

4.3. SSIM and UQI

The Structural Similarity Index (SSIM) is a perceptual measure that measures picture quality debasement because of preparing like information pressure or transmission misfortunes. It is a full reference measure that requires two pictures—a reference picture and a processed picture—from a similar picture catch. Utilizing eq, SSIM might be resolved mathematically (4).

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad (4)$$

Universal Image Quality Index (UIQI) is a proportion of how great a picture is in the wake of inserting. UQI utilizes loss of a relationship, luminance contortion, and differentiation twisting to evaluate picture quality. UQI can be determined numerically via Eq. (5).

$$UQI = \frac{4 \sigma_{xy} \bar{x} \bar{y}}{(\sigma_x^2 + \sigma_y^2) [(\bar{x})^2 + (\bar{y})^2]} \quad (5)$$

SSIM and UQI are given in Table 2

Table 2 SSIM and UQI values for stego-images generated via StegoBound

S.no	Image	SSIM	UQI
1	LENA (512x512)	0.9953	0.9998
2	MANDRILL (512x512)	0.9985	0.9998
3	HOUSE (256x256)	0.9956	0.9998
4	BLUEHILLS (128x128)	0.9984	0.9996
5	BOAT (512x512)	0.9968	0.9998

The results of SSIM and UQI obtained from the StegoBound technique are of high quality as both the SSIM and UQI for every stego image formed by StegoBound is approximately 1. 1 means that the stego image and original image are the same.

4.4. Comparison

A comparison of the PSNR findings achieved via StegoBound (Table 1) with the PSNR values of other steganography techniques can validate the superiority of the intended StegoBound approach over other state-of-the-art techniques (discussed in section 2). Table 3 indicates the outcomes of the comparison analysis.

Table 3 Comparative analysis of StegoBound with state-of-the-art techniques in terms of PSNR

S.#	Technique	Category	Image	Type	PSNR
1	[15]			Grayscale	49.37
2	[16] 1-bit scheme			Color	51.63
3	[16] 2-bit scheme			Color	49.90
4	[19]			Color	50.93
5	[21]	LSB		Color	46.64
6	[22]			Color	43.63
7	[23]			Color	47.51
8	[28]			Color	47.5897
9	[29]			Grayscale	40.81
10	[34]		Lena (512x512)	Color	39.566
11	[35]			Grayscale	42.26
12	[36]			Color	42.447
13	[37]	MSB		Grayscale	51.17977
14	[38]			Grayscale	57.58
15	[39]			Color	53.7317
16	[40]			Color	48.0002
17	[42]			Color	54.27
18	[43]	Hybrid		Color	62.73
19	StegoBound	LSB		Grayscale	64.154

S.#	Technique	Category	Image	Type	PSNR
20	[15]			Grays cale	49.38
21	[16] 1-bit scheme			Color	51.64
22	[16] 2-bit scheme			Color	49.88
23	[21]			Color	40.26
24	[22]	LSB		Color	38.33
25	[23]			Color	45.13
26	[26]			Gray	32.6719
27	[28]		Mandrill	Color	36.3637
28	[29]			Grays cale	41.74
29	[34]			Color	39.573
30	[36]			Color	42.451
31	[37]	MSB		Grays cale	51.1803
32	[39]			Color	53.7882
33	[40]			Color	61.7972
34	StegoBound	LSB		Grays cale	72.439
35	[22]	LSB		Color	41.22
36	[23]		House	Color	46.77
37	StegoBound	LSB		Grays cale	72.552
38	[22]	LSB		Color	41.30
39	[23]		Boat	Color	46.42
40	StegoBound	LSB		Grays cale	64.6688
41	[33]	MSB		Grays cale	41.367
42	StegoBound	LSB	Bluehills	Grays cale	68.047

Table 3 reveals that our proposed StegoBound technique achieves the best PSNR values for the generated stego-images compared to all the techniques.

4.5. Robustness

StegoBound is also strong against statistical strikes and offers better security against steganalysis attacks. By evaluating the means values of the original cover photos and the generated stego-images, as well as through histogram analysis, the security of StegoBound may be verified. Better security is ensured by a little difference in the mean values of the two photos. Table 4 shows the mean values of the original cover images and the stego-images generated utilizing StegoBound.

Table 4 The mean values of StegoBound stego-images and original cover images

S.#	Image	Original Image	Stego Image
1	Lena image	124.0504	124.0502
2	Mandrill image	138.7426	138.7425

S.#	Image	Original Image	Stego Image
3	House image	137.9846	137.9855
4	Bluehills image	124.1266	124.1108
5	Boat image	129.7079	129.7077

The mean values of the stego-images and original images are practically identical and do not differ much, implying that StegoBound delivers greater security, as shown in Table 3. StegoBound is also resistant to histogram steganalysis, as seen in Figs. 1 and 2, where the histograms of the cover picture Lena and the generated stego-image are nearly similar and show no noticeable variations. 6–7

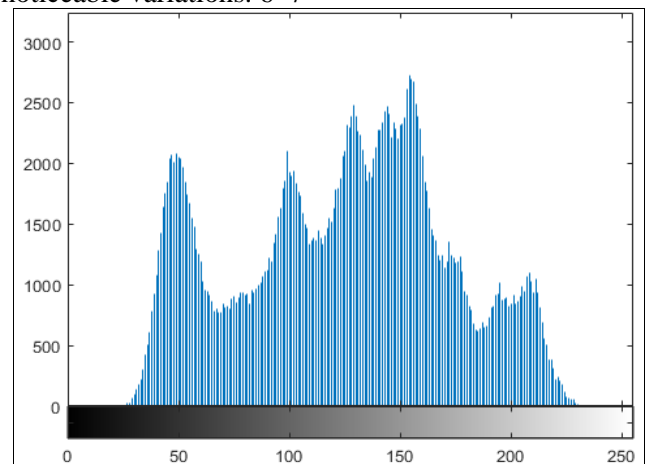


Fig. 6 Histogram of cover image Lena

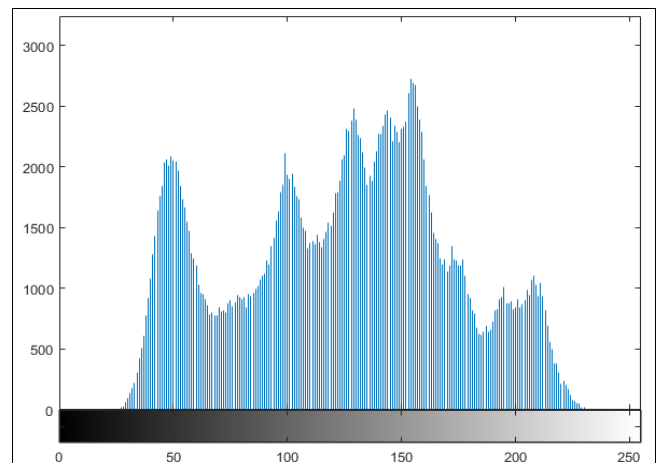


Fig. 6 Histogram of stego image Lena

5. Conclusion and Future Works

We introduced a new steganographic methodology in this study paper. With 3 LSBs, StegoBound used boundary-based LSB replacement to insert the hidden message in the cover image. Our proposed technique achieves an optimal trade-off for the key steganographic parameters. It delivers state-of-the-art results with high imperceptibility, payload capacity, and robustness compared to other existing methods.

In the future, we intend to extend StegoBound for RGB images and explore MSB and hybrid substitution techniques for embedding the secret messages.

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