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Reversible Data Hiding in Image Steganography using Improved Histogram Shifting Algorithm

Pooja Kaur[1], Kulwinder Singh[2]
[1]Research Scholar, Department of CSE, Bhai Maha Singh College of Engg., Sri Muktsar Sahib
[2]Professor, Department of CSE, Bhai Maha Singh College of Engg., Sri Muktsar Sahib.

Abstract: Due to advancement in the information technology, the data communication over the internet is increased. Therefore, the data is prone to unauthorized access and tempering attacks. To solve these problems, the security fields like cryptography and steganography are being used. To provide confidentiality, the cryptography algorithm scramble the secret data using a secret key and gives the encrypted data in the output, whereas steganography algorithms hide the secret data in the cover image and gives the stego image in the output. In the cryptography, the scrambled data gives attention to the attacker whereas steganography provides imperceptibility to the attacker by hiding the data in the cover image. Therefore, in our research, we have chosen the steganography algorithms for data security. In the steganography, least significant bit (LSB) algorithm is the most preferred algorithm. In this algorithm, the cover image is read and its pixels are extracted. After that, least significant bit of the pixels is replaced with data bits. The challenge of the LSB algorithm is that the cover image is not reconstructed after data extraction. Therefore, we may choose histogram shifting algorithm in which cover image is reconstructed after data extraction. In present research work, an improved histogram shifting algorithm is designed in which the variability is generated due to reduced data hiding. In order to achieve this goal, the data bits are flipped if the variability between the cover image and stego image is greater than 50%. The experimental results are performed on the standard dataset images downloaded from USC-SIPI-Digital Image Repository. After that, various performance parameters like Mean Square Error, Peak Signal to Noise Ratio, Embedding Capacity & Normalized Cross-Correlation etc. are calculated and compared with the existing algorithms. The results prove the competency of proposed algorithm over the existing algorithms.

Keywords: Image Steganography, Histogram Shifting Algorithm, Least Significant Bit Algorithm, Mean Square Error, Peak Signal to Noise Ratio.

1. Introduction

Information and data security has been a major challenge in the telecommunications industry ever since the internet is developed. This can be done by protecting information or channels. Cryptography is introduced as a technique for ensuring the privacy of communications, and various techniques have been developed to encode and decode information to encrypt messages. Unfortunately, confidentiality may not be enough. We therefore need to keep the information confidential. To encounter this problem, steganography technique was developed [1]. We keep confidential and personal information part of our daily lives, regardless of work or personal well-being. As a result, the safe storage and transmission of confidential information has attracted the attention of many researchers. Steganography is a way of storing sensitive data through unobtrusive digital media, for example video, audio, and sometimes both together. Of the various types of media, digital images are the most common and available, and this study focuses on the implementation of digital image steganography [2].

Steganography as well as watermarks are both used for hiding the secret messages and are closely linked, but both have separate purposes. The major purpose of steganography is to protect the confidential information during communications. A watermark, on the other hand, is utilized for protecting the integrity of sensitive information, whether or not it conceals the presence of any communication between the eavesdropping devices. The major purpose of the Watermark program is for protecting the intellectual property of the sensitive information [3].

The three major terms used in the steganography are insurance information, confidential information and cryptographic algorithms. A confidential information system can be deployed to ensure secure communication. Scope information refers to information such as images, videos, audio, text, or other digital media. Confidential information is important information to hide on the appropriate digital media. Depending on the encryption algorithm, the

encryption key is often used to enter information. Additional algorithms are ideas or techniques used to encrypt sensitive, insured information [4].

Histogram-based data encryption is also widely used steganography technique. Histogram transformation is considered as one of the most effective histogram application scheme and contains the following parameters: First, it looks at the dots and empty lines in the cover image, and the grass rotates from a single level between zeros and vertices [5]. To add functionality, the cover image is split into 5x5 without an image board. In every block, the middle pixel is considered as the base pixel of the system prediction process, and the other pixels are built within the block to produce the remaining values. The histogram system is used to modify the histogram to store sensitive data. In addition, use some pairs of zeros and vertices to modify the histogram for increasing the input. In alternative method [6], the histogram of the 2D system was changed to a two-part separation system. With this method, the conversion performance depends on the pixel selection method. The pixel selection method allows you to find the target pixel in the appropriate area. In short, this feature works better with graphics than with solid text images.

The rest of the structure is as follows. Section 2 presents the related work on image steganography. Section 3 illustrates the proposed methodology. Section 4 shows the results and analysis. Finally, the conclusion is drawn in Section 5.

2. Related Work

Steganography is the extensively utilized technique for sending the digital images over internet using numerous media applications. Steganography conveys the digital information encrypted in the image over a large number of mediums, so as not to fascinate the attention of billions of users from the Internet. Consequently, steganography is a commonly used research topic because various communication applications have tremendous potential to improve communication security [7].

Zhang et al. (2001) introduced a class of input methods called Quantized Index Modulation (QIM). As per the authors, QIM data does these perfectly use the two different numbers of machines. One of the two numbers is utilized in the DCT coefficient and the second number is utilized to correct the first. QIM works well for channels that are quiet and prone to channel interference [8]. **Li and Wang (2007)** developed a Particle Swarm Optimization (PSO) algorithm, which is based on the technique of JPEG steganography. System was developed to encrypt sensitive data in the mid-frequency range of DCT coverage [9]. In JPEG steganography, **Liu and Liao (2008)** demonstrated the additional ability to divide DCT and coefficient coefficients into two groups depending on the size of the linear regression model. The relevant section is added to the secret by subtracting one using two DCT numbers or accumulating one to a non-zero DCT number [10]. **Reddy and Raja, (2009)** developed integration-based DWT steganography. Encrypt the load number, link it to the shell coverage speed, and create a stego level based on the alpha and beta characters. Compensation and compensation will be adjusted to reduce pixels to ensure accurate compensation and destination [11]. **Kumari et al. (2010)** developed data encryption and steganographic integration and encrypting algorithms. The ciphering key is secretly encrypted and the data entry section is placed in the change section. It makes a number of small, often rejected, changes to the characters associated with the entry. Inputs are used to decide whether to place them on a block or an image [12]. **Hamid et al. (2012)** developed an integrated system that combines the cosine discrete change (DCT) system and the LSB system. Prior to application, the confidential information was encrypted and the covered material was modified using DCT and LSB methods that use each pixel. Branched cosine conversion (DCT) in which the cover plate is divided into 16x16 pixels without pre-amplification. The modified DCT size is calculated in a 16x16 quantization table. Every DCT block is assigned with at least two LSB values (2 LSB) for each variable. However, the level of Stego will increase [13]. The objective visual effects of unpredictable loss data systems in the solar system were developed by **Kanan and Nazeri (2014)** on the basis of genetic algorithm (GA). When compared to other popular steganography systems today, experimental results show that the required algorithm is capable of achieving higher processing power, increased PSNR of higher stego images [14]. **Jiang et al. (2016)** developed a KUUM steganography system that encrypts confidential information in different layers as images. It requires two sets of LSB steganography algorithms and a quantum circuit system based on a newly enhanced Quantum Representation (NEQR) system for enhancing quantum images. This algorithm is the standard LSB that uses the network to replace the pixel LSB. Other is the LSB block, which sends the message to the image block in multiple pixels [15]. **Usman et al. (2018)** suggested a new approach for image steganography for the

protection of medical data. Interchangeable Huffman tree coding is used for applying the lossless compression, afterwards manifold encryption is applied to the payload before embedding it on the cover image. In addition, only the cover image's edge area is utilized for embedding the sensitive data [16]. Hidden images and other images are analyzed by **Elharrouss et al. (2020).** Based on the LSB code, the k-LSB-based method of hiding the image is recommended. To resolve hidden images, use the local discovery service to determine if the block contains hidden images. The image enhancement system is used to optimize the image because the resolution of the steganography can be affected [17]. A novel system quick response method (QRM) is suggested by **Peter et al. (2022)** for encryption as well as decryption. Side match vector quantization (SMVQ) scheme is utilized in the existing system which offers a few challenges like security and performance issues. For handling the security as well as performance issues, two approaches are utilized by suggested system such as shifting approach and quick response approach [18]. **Fatman et al. (2023)** developed the prevailing data hiding techniques by enhancing their capacity to hide variable sized covert data. The suggested approach leverages the bottom and right context pixels to develop a better data hiding technique [19]. **Kamil Khudhair et al. (2023)** recommended a new scheme for obtaining the distribution of a cover image for determining the pixels to obtain a zero or peak distribution. Afterwards, the neighboring bins of histogram with peak points are then shifted. Embedding of the data is accomplished by utilizing the LSB scheme for peak pixels in the image [20]. A novel approach of image steganography is presented by **Elqolby et al. (2024).** This technique inserts the secret data bits by using the histogram shifting and edge-based fuzzy logic. An efficient and robust solution is provided by the proposed technique for secret data hiding as well as its retrieval in the images with minimal distortion [21]. **Tan and Fu (2024)** introduced a novel reversible data hiding algorithm to restrict the histogram shifting in a confined range. Thus, the image quality is stabilized by minimizing the pixel modification sizes. For enhancing the histogram peaks and expanding the capacity of image embedding, an optimal difference retrieving technique is utilized [22]. **Xiao et al. (2025)** explored the strength of Robust Reversible Watermarking (RRW) technique by simultaneously enhancing the reversibility and watermark resilience. A histogram-shifting algorithm with JPEG compression-resistant is proposed that can withstand the targeted compression [23].

3. Proposed Methodology

The suggested algorithm is simple and delivers improved visual quality. Block diagram of this proposed algorithm is indicated in Figure 1. Initially, the cover image was read and its histogram is plotted. Following this, the peak and zero values of the histogram were determined. Then the adjacent bins of the histogram with peak value were moved to zero. Then, secret data was read and hide in cover image's peak value using LSB algorithm that provides a stego image in its output. After data hiding, the absolute difference (AD) and threshold (T) value were determined using Eq. (1) and (2). Secret data will be flipped if the value of absolute difference is greater than its threshold value, then LSB algorithm is utilized to hide the cover image in peak value.

$$AD = (Absolute_Difference(C, S)) \quad (1)$$

$$T = \frac{P}{2} \quad (2)$$

Where, C, S signifies the cover as well as the stego image and P denote the peak value of the histogram. Next, the detailed explanation of histogram shifting reversible method and the flipping algorithm is explained.

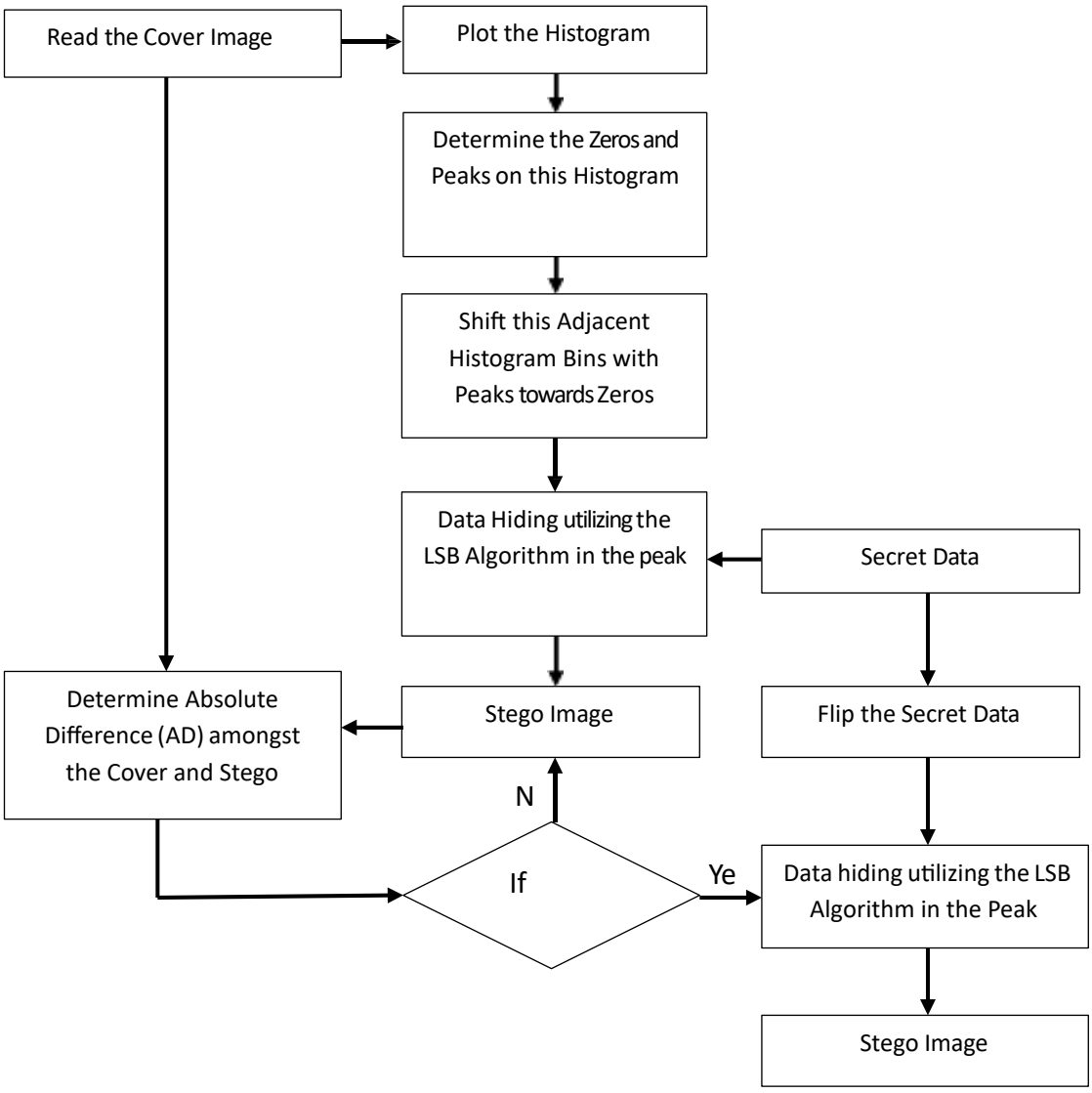


Figure 1: Block Diagram of Suggested Algorithm

3.1 Histogram Shifting Reversible Method

The histogram shifting reversible method analyses the cover image histogram for data hiding. The histogram signifies a pictorial view of number of pixels versus the values of grey level, as shown in Figure 2. The x-axis denotes the pixel value whereas y-axis shows number of amplitude. In our work, we have worked on grey scale images. In these grey-scale images, each pixel is 8-bit long. Consequently, maximum 2^8=256 grey level representation is possible in the histogram. The pixel values are ranging from 0 to 255. Here, 0 values represent the black color and 255 values represent the white color. The pixels in between these values show the different level of grey value. In the histogram shifting reversible method, the pixels are determined which represents the peak amplitude and zero amplitude. For example, in the Figure 2, the 154 pixels represent the maximum amplitude 211 whereas 25 and 235 pixel represents the zero amplitude.

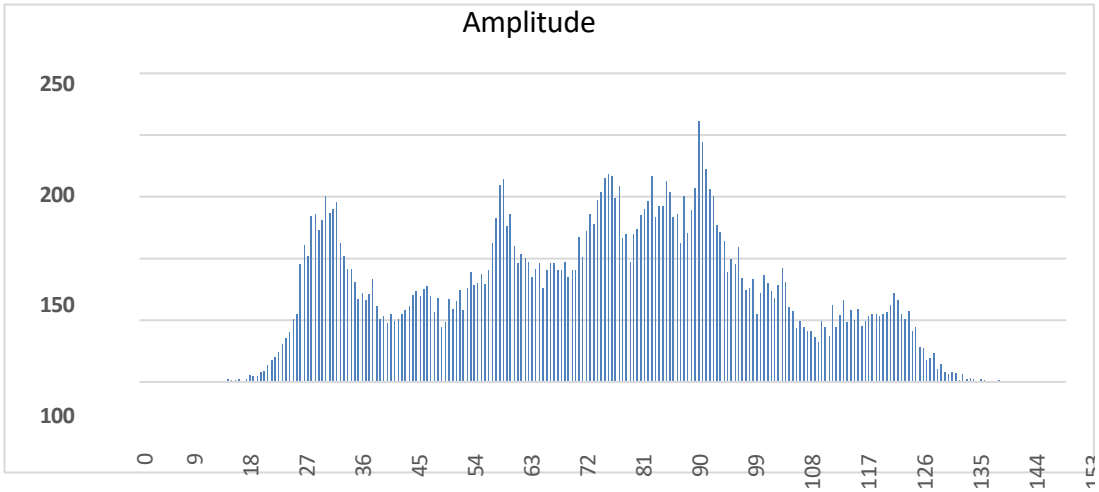


Figure 2: Sample Histogram

3.2 Flipping Method

The histogram shifting reversible method generates the variability if the LSB bit of the peak pixel and data bits are not matched with each other. In order to match the bits, we have used a simple method known as flipping method. The flipping method inverts the original bit before data hiding. Let, the secret data is 10010010. The flip method inverts the secret data and changed into 01101101, as shown in Figure 3. In the recommended scheme, initially, one time data hiding is done in the peak pixel. After that, its variability is determined. If the variability is higher than the threshold value, then, all secret data bits are flipped. In our method, we have taken threshold 50%. Besides that, the data security is improved because difficult to determine to the attacker data is in original form or flipped form hide.

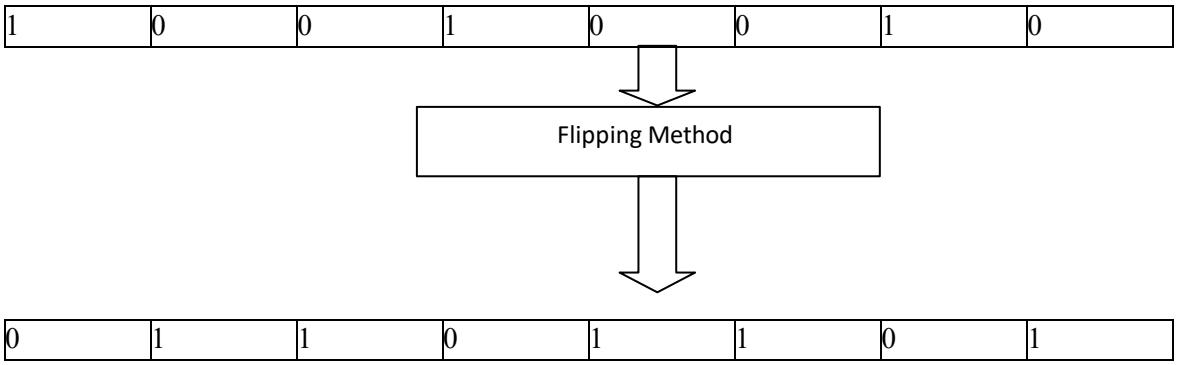


Figure 3: Flipping Method

3.3 Data Extraction for the Proposed Method

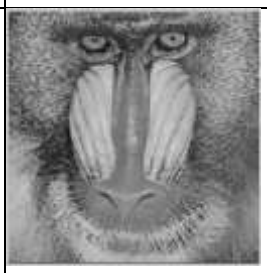
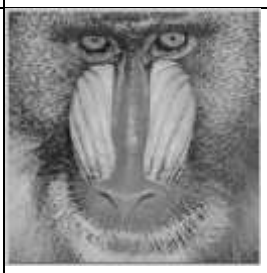
In the receiver, the stego image is read alongside with peak, zero bit, and flipping value. Then, the extraction of secret data bits is achieved from the adjacent and peak histogram bin values. Next, based on the flipping value, original secret data bins are recovered. Further, to recover the original cover image, these histogram bins are moved towards peak value from zero value.

4. Results and Analysis

4.1 Qualitative Analysis

Qualitative analysis is basically a visual analysis to compare and perform results of cover and stego image. Different cover images are chosen from standard dataset available, a qualitative analysis is performed for these images and results are summarized in Table 1. The results indicate the similarity between cover and stego images after data hiding in them. As we can see that the both images look same and cannot be distinguished by naked eye.

Table 1: Visual Quality Analysis to compare Cover and Stego Image

Image	Cover Image	Stego Image
Lena		
Baboon		
Barbara		
Pepper		
Female		

4.2 Quantitative Analysis

Quantitative analysis is performed by comparing the cover and stego images using multiple performance parameters for the proposed algorithm as well as existing algorithm (Histogram Shifting Algorithm). Different performance parameters selected for comparison are selected and explained as follows:

- **Mean Square Error (MSE)**

This parameter measures the mean square error amongst the cover and stego images that were generated after the data hiding. It is calculated using Eqn. (3) as follows:

$$\text{MSE} = \frac{\sum_{x=1}^{M}\sum_{y=1}^{N}(C_{xy}-S_{xy})^2}{MN} \quad (3)$$

Where M, N denotes the number of rows and columns of cover image respectively, C, S represents the cover as well as stego images respectively. In the last, x, y represents the subscripted variables.

The MSE values for different images for histogram shifting algorithm and proposed algorithm is summarized in Table

2. The results show that Lena provides minimum MSE and pepper highest, as shown in figure 4. This shows that for all other images (except Lena Image), the variability between cover and stego image is higher than 50%.

Table 2: Comparative Analysis of Mean Square Error between the Histogram Shifting Algorithm and Proposed Algorithm

Image	Histogram Shifting Algorithm	Proposed Algorithm
Lena	0.2816	0.2811
Baboon	0.5673	0.5673
Barbara	0.6039	0.6039
Pepper	0.6289	0.6284
Female	0.5066	0.5065

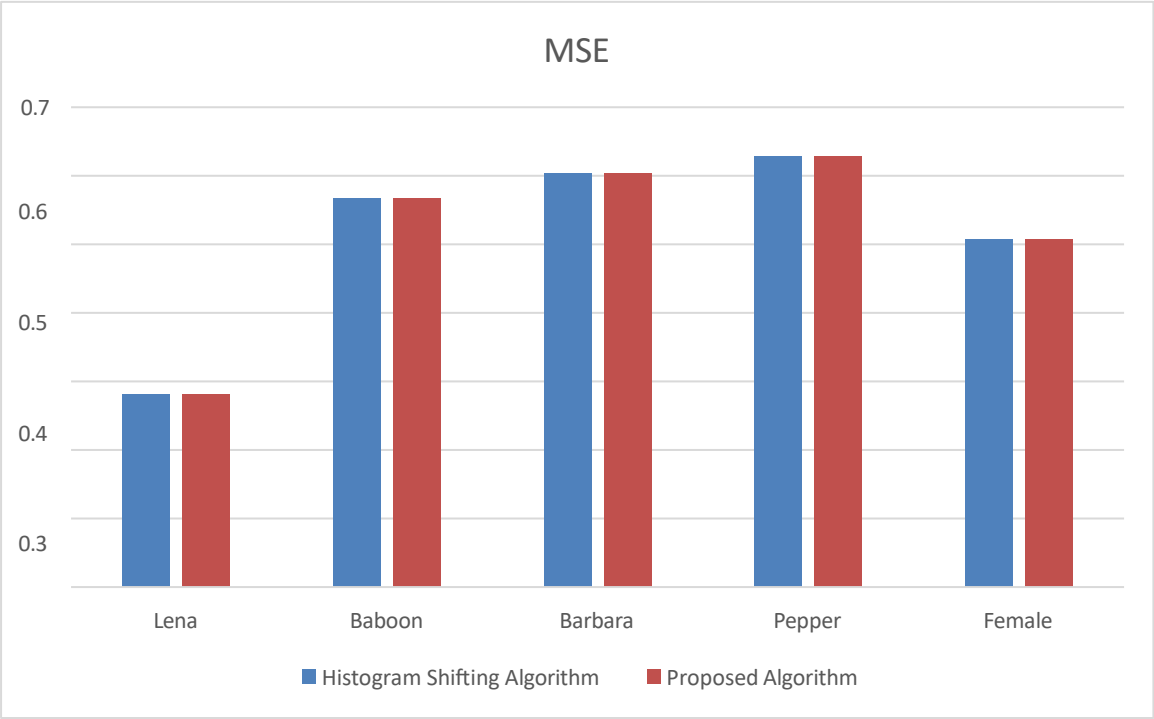


Figure 4: Comparative Analysis based on MSE parameter

- **Peak Signal to Noise Ratio (PSNR)**

PSNR is used to measure the stego image's quality after data hiding in it. Eqn. (4) is used to calculate PSNR values for different stego images.

$$\text{PSNR} = 10\log_{10}\frac{P^2}{\text{MSE}} \quad (4)$$

Where, P represents the highest pixel value obtained from the stego image. Maximum pixel value for a grayscale images is 255. The PSNR values for different images for histogram shifting algorithm and proposed algorithm is summarized in Table 3. The results show that Lena provides highest PSNR value whereas pepper provides lowest, as shown in figure 5.

Table 3: Comparative Analysis of PSNR (in dB) between the Histogram Shifting Algorithm and Proposed Algorithm

Image	Histogram Shifting Algorithm	Proposed Algorithm
Lena	53.6338	53.6429
Baboon	50.5930	50.5930
Barbara	50.3210	50.3210
Pepper	50.1450	50.1481

Female	51.0842	51.0847

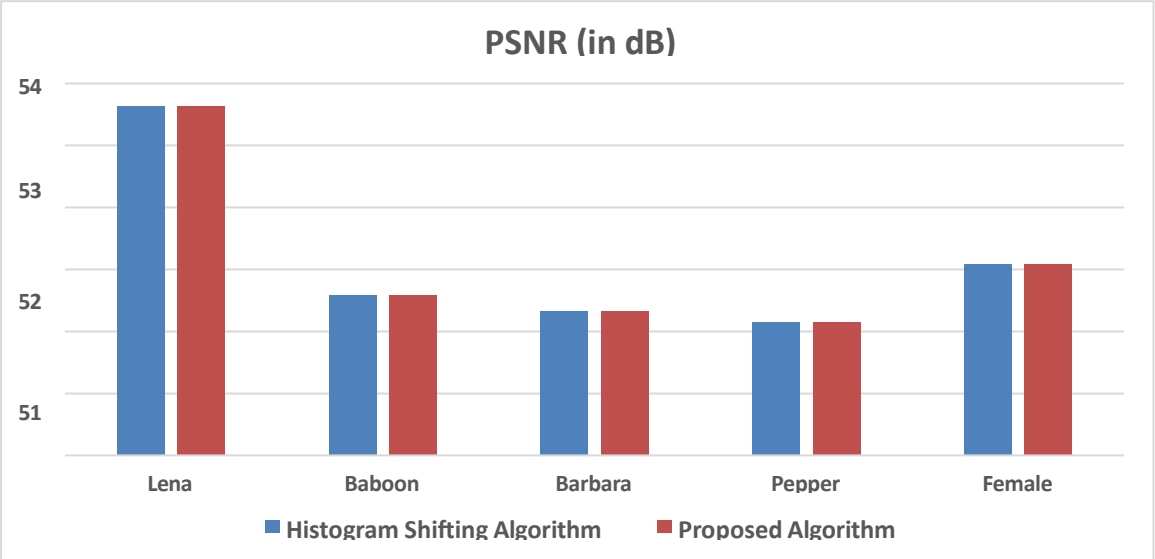


Figure 5: Comparative Analysis based on PSNR Parameter

- **Embedding Capacity**

Embedding capacity is used to calculate the maximum quantity of bits that can be hidden in the given cover image to obtain a stego image. It is calculated in bits. Embedding capacity values for different images for histogram shifting algorithm and proposed algorithm is summarized in Table 4. The results indicate that the *Female* image attains the highest value of embedding capacity whereas *Barbara* image attains the lowest, as shown in Figure 6. Besides that, the existing histogram shifting algorithm and proposed algorithm provide the same embedding capacity.

Table 4: Comparative Analysis of EC (in bits) between the Histogram Shifting Algorithm and Proposed Algorithm

Image	Histogram Shifting Algorithm (in bits)	Proposed Algorithm (in bits)
Lena	727	727
Baboon	744	744
Barbara	669	669
Pepper	805	805
Female	1228	1228

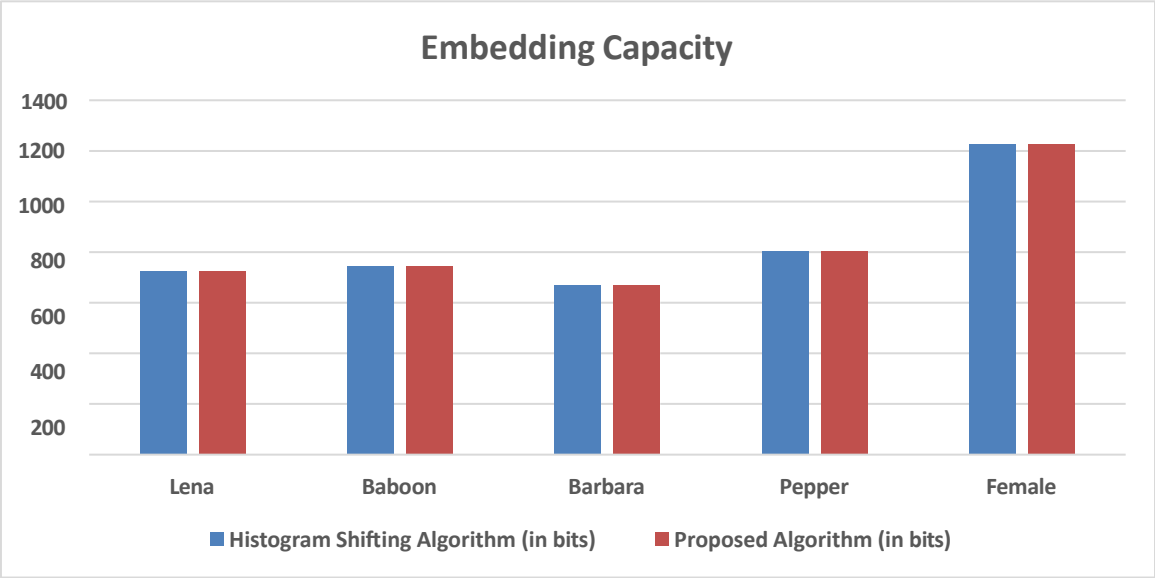


Figure 6: Comparative Analysis based on Embedding Capacity Parameter

- **Normalized Cross-Correlation (NC)**

Normalized Cross-Correlation (NC) is used to measure the demographic changes that may occur between a cover and a stego. The value of NC is varied between -1 to 1. NC value of '1' infers that the cover as well as stego images are completely similar, whereas '-1' value represents that the cover as well as stego images are complement of each other. Eq. (5) is used to determine the value of NC as follows:

$$NC = \frac{\sum_{m=1}^{J}\sum_{n=1}^{K}(C_{mn}-C_{mean})(S_{mn}-S_{mean})}{\sqrt{\sum_{m=1}^{J}\sum_{n=1}^{K}(C_{mn}-C_{mean})^2 \sum_{m=1}^{J}\sum_{n=1}^{K}(S_{mn}-S_{mean})^2}} \quad (5)$$

Here C, S represents the cover as well as stego images respectively. C_{mean}, S_{mean} represents the mean values of cover as well as stego images respectively. J, K denotes the subscripted variables. NC values for different images for histogram shifting algorithm and proposed algorithm are summarized in Table 5. The results indicate that both the proposed algorithm as well as Histogram Shifting algorithms obtains the NC value equal to 1 for all the standard images as shown by Figure 7.

Table 5: Comparative Analysis of NC between the Histogram Shifting Algorithm and Proposed Algorithm

Image	Histogram Shifting Algorithm	Proposed Algorithm
Lena	1.000	1.000
Baboon	1.000	1.000
Barbara	1.000	1.000
Pepper	1.000	1.000
Female	1.000	1.000

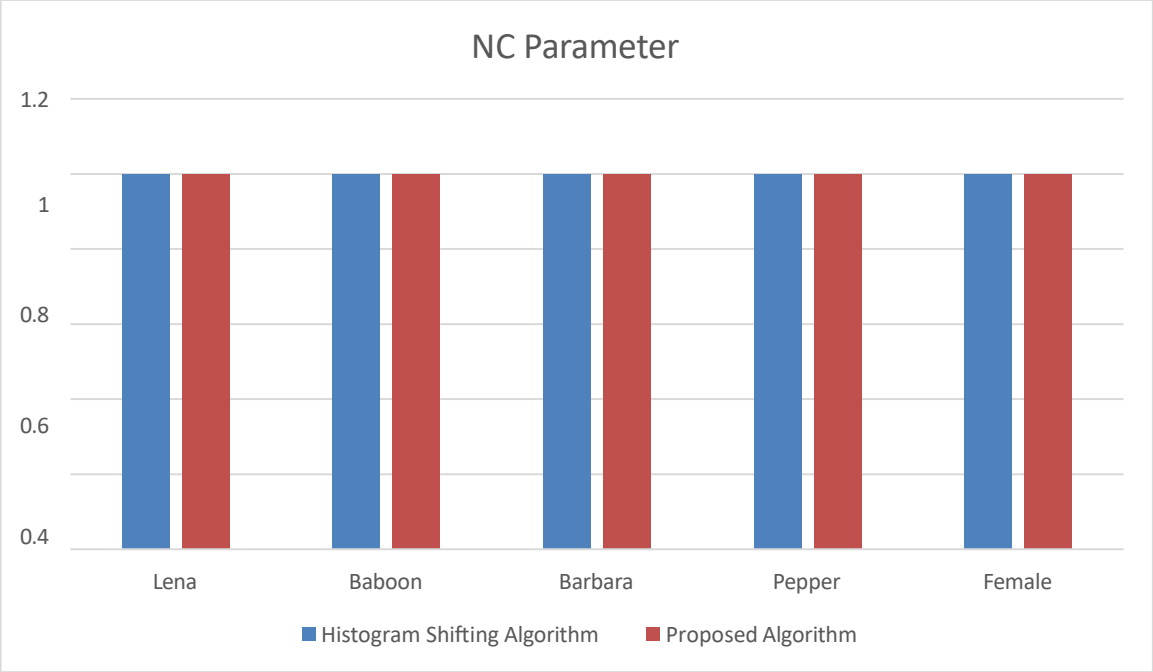


Figure 7: Comparative Analysis based on NC parameter

- **Normalized Absolute Error (NAE)**

Normalized absolute error is used to calculate the value of absolute error amongst a cover and a stego image. A low NAE value is required in steganography. NAE value is calculated by using Eq. (6) as follows:

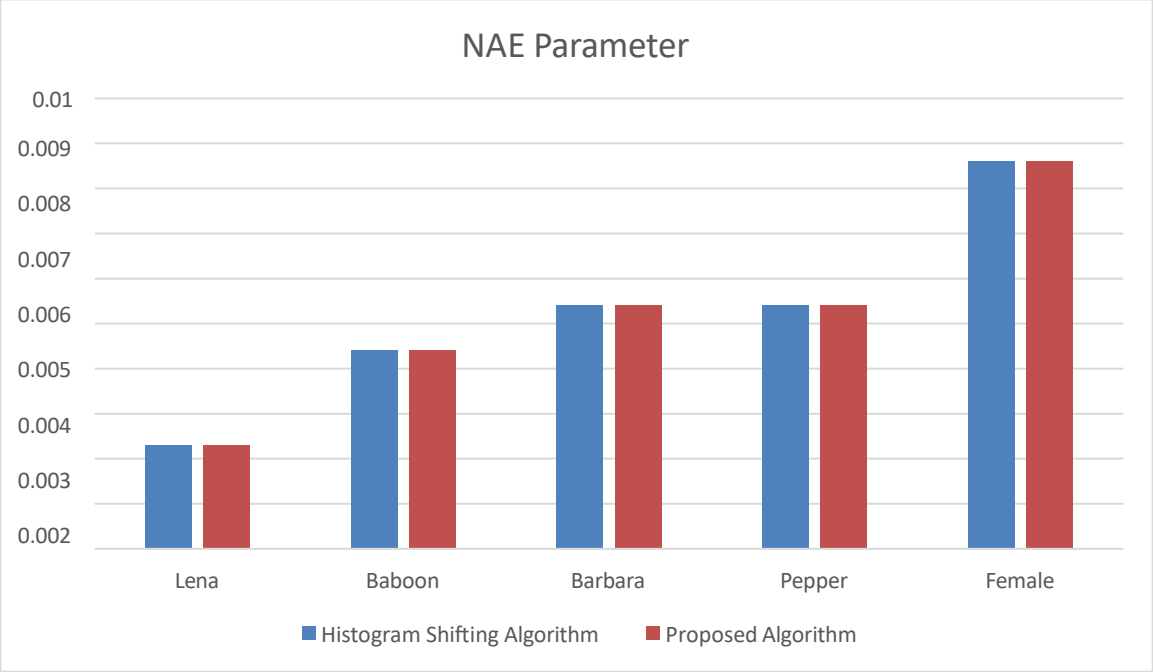
$$\text{NAE} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}|C_{ij}-S_{ij}|}{\sum_{i=1}^{M}\sum_{j=1}^{N}C_{ij}} \quad (6)$$

Where M, N denotes the number of rows and columns of cover image respectively, C, S represents the cover as well as stego images respectively. NAE values for different images for histogram shifting algorithm and proposed algorithm are summarized in Table 6. Lowest NAE value is obtained for the Lena image, whereas highest NAE value is obtained for female image as shown in Figure 8. Besides that, the existing histogram shifting algorithm and proposed algorithm provide the same NAE value for all the images.

Table 6: Comparative Analysis of NAE between the Histogram Shifting Algorithm and Proposed Algorithm

Image	Histogram Shifting Algorithm	Proposed Algorithm
Lena	0.0023	0.0023
Baboon	0.0044	0.0044
Barbara	0.0054	0.0054
Pepper	0.0054	0.0054
Female	0.0086	0.0086

Figure 8: Comparative Analysis based on NAE parameter



5. Conclusion

In this study, the variability is reduced for the histogram shifting algorithm without degrading the embedding capacity. To achieve this goal, the peak values as well as zero values for the existing histogram algorithm are determined. After that, adjacent pixel bins of obtained peak values are moved towards the zero values. Next, LSB algorithm is utilized to hide the secret data in a cover image to obtain the stego image. After that, the variability amongst the given cover and obtained stego image is calculated. If this variability amongst the given cover and obtained stego image is more than 50% then the secret data is flipped else no flip operation is performed over the secret data. A comparative analysis for standard Histogram Shifting Algorithm and proposed algorithm is performed for all the selected cover images using different performance parameters such as MSE, PSNR, EC, NC and NAE. The results indicate that the proposed algorithm provides lesser MSE values and better PSNR values when compared with existing histogram shifting algorithm for the images such as *Lena*, *Barbara*, *and Female*. However, EC, NC and NAE values are similar for both the proposed and existing algorithms.

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