Journal of Scientific Research & Reports
9(3): 1-14, 2016, Article no.JSRR.19518
ISSN: 2320-0227

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Analysis of Steganography Techniques using Least Significant Bit in Grayscale Images and its Extension to Colour Images

Aqsa Rashid[1], **Malik Muhammad Saad Missen**[1] **and Nadeem Salamat**[2*]

[1] *Department of Computer Science and Information Technology, The Islamia University of Bahawalpur, Pakistan.*

[2] *Department of Mathematics and Statistics, Karakoram International University, Gilgit, Pakistan.*

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2016/19518

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Complete Peer review History: http://sciencedomain.org/review-history/11856

Review Article

Received 13th July 2015
Accepted 5th September 2015
Published 17th October 2015

ABSTRACT

Image steganography conceals the furtive information into images in such a way that perceptually images are impossible to differentiate and visual features remains similar, but statistical features have some alteration. This method are developed for the secure communication over the internet. In this paper, the sequential Least Significant Bit (LSB) substitution method for every possible location in pixel is analyzed. The statistical measures compute the image quality. These measures show that message substituted in the eighth bit (Least bit) has the fewer visual and statistical effects on the image quality.

**Corresponding author: E-mail: nadeemsalamat@hotmail.com*

Keywords: Stegnography; LSB techniques; LSB; statistical measures for comparison.

2010 Mathematics Subject Classification: 53C25; 83C05; 57N16.

1. INTRODUCTION

Communication over the Internet is the key point for many researchers and counter terrorism organizations attributed to the global terrorism phenomenon. These organizations use the Internet as communication tool to send or receive information among parties and data hiding techniques are used for the covert communications. These techniques can also be used for conveying a computer virus or Trojan horse programs via data hiding techniques. The data communication over the Internet have the risk of third person probing and conversely, it is equally important to probe and intercept or block this type of communication over the Internet. The secure communication over the Internet has the fundamental importance for the countries or security organizations. The stegnography techniques are developed to deceive such organizations by embedding messages into images in an imperceptible manner preserving their original formats and quality, meanwhile, the steganalysis methods are developed to intercept or block such activities. The communicated message substituted in images led to development of image steganography technique. In these techniques, the objective is to hide the existence of message in an image that can escape through the filters imposed by the counter parties, while communicated through the Internet ([1, 2], [3], [5, 4, 6]).

In image steganography, the message is hidden in an image. The various techniques have been developed for this purpose, for example, edge based stegnography, Least Significant Bit (LSB, 8^{th}) technique ([7, 8]) ([9]), it is further divided into two parts, LSB substitution techniques and LSB-histogram matching technique ([10]). In sequential LSB substitution method, the message bit is replaced by the least significant bit of the pixel one by one ([5, 11]). The process of substitution continues until the length of the message bits becomes zero. This can be applied on both the gray scale and color image.

Grayscale images have 8 bit per pixel images. They have one byte per pixel to represent all the 256 gray shades. In such images one bit per pixel is used to substitute the message bit. In colored images, each channel has 8 bit width and the message bit can be hidden into any one of the three channels or all the three channels of image ([12]). This increases the space for the substation of the message, i.e., We can replace three bits per pixel from such images each from red, green and blue byte. The effect of change in the stego images is measured with the statistical measures for the comparison of signals and images ([13, 14, 15]).

The steganalysis systems are capable for detecting the stego-images and identify the suspicious contents. These systems can increase the cyber security. These systems make decisions about the presence or absence of stago-images. It is simple if we have the original image and suspected objects can be detected by comparing these images. The substituted messages into an image cannot be intercepted by naked human eyes but there are some detectable artifacts in the images depending on the algorithm used for steganography ([16, 17]) . This paper is concerned with the analysis of substitution method in LSB and steganalysis methods, in each bit of the image and its impact on the quality of the image.

The paper is arranged as follows. In Section 2 , a stego system is discussed. A theoretical analysis system is described in this section. Image quality measuring tools for comparison are described in Section 4. The Section 5 composed of the experimental results and discussion, Section 6 concludes the paper.

2. STEGO SYSTEM

A stego-System in image steganography is a system that is able to conceal a clandestine message within an image. The stego-method is, not only able to embed the message, it also makes it achievable to read the hidden message at the receiver side. Algorithms for both the embedding and extraction of the message are as following:

Algorithm 0.1. *Embedding steps for sequential LSB Substitution Stego-method are*

1. *For* $j = 1, 2, \ldots, l(m)$
2. $lsb = LSB(p_j)$
3. *If* $lsb \neq m_j$ *then*
4. $lsb \leftarrow m_j$
5. *end if*
6. *end for*

$l(m)$ Contain the message bits. It first takes the pixel p_j of the image and its $LSB(p_j)$ value. If the number is even the lsb will be 0 and a 1 if the number is odd. We then contrast this with the message bit m_j. If they are the same as before, then nothing to be done, but if they are dissimilar, it should change lsb with m_j. This process goes on even as $l(m)$ is not zero.

Algorithm 0.2. *Extracting steps for sequential LSB Substitution Stego-method*

1. *For* $j = 1, 2 \ldots, L(s)$
2. $rm_j \leftarrow (s_j)$
3. *endfor*

$L(s)$ is the total number of pixels of supposed image. Run the loop $L(s)$ in place of $L(m)$. This is because the embedding is different from the retrieval process. We just recover the LSB value of each pixel rm and translate this to ASCII; the message will be understandable and in readable format up to the point that the message was embedded, and will then come into view as claptrap when we see the LSBs of the image data. If we know the length of the message that was embedded, then the loop will be ended when the length of message is completed and only the message will be retrieved.

3. STEGANALYSIS FOR SEQUENTIAL LSB SUBSTITUTION

This section is concerned with the steganalysis of the substitution techniques. The result of steganalysis system depends on what the steganalyst desires to realize. For example, one steganalyst might just desire to identify whether two parties are communicating or not. Whereas another steganalyst might desire to identify and intercept the communication between two parties.

Image Steganalysis system first detects that whether the image is a stego-image or not. After detecting the communication, the decision is taken for further processing i.e. to modify the message or completely destroy the message. For the sequential LSB substitution steganography some steganalysis methods are:

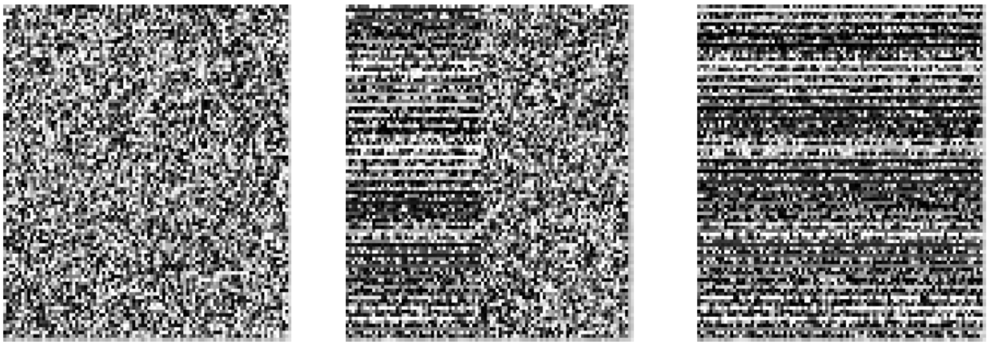
3.1 Visual Attack

The LSB substitution replaces the LSBs of the image with the bit stream of the message in series until the entire message had been embedded. Visual attack recognizes whether or not a supposed image has been subjected to this kind of embedding, the steganalyst will be looking to obtain a visual inconsistency for the first L pixels where L is the length of the message. It is value nothing though, that the accurate value for L will not be made visible until the visual attack successfully points out signs of embedding.

Fig. 1 shows the case of a visual attack. It shows the LSB plane (Fig. 1(a)) a cover image, and (Fig. 1(b)) an image that is supposed to be the stego-image using LSB substitution technique. Image 1(b) clearly shows that almost 50 percent of the LSBs do not look as organized as the latter half of the image and it is the conformation of alternation. Image (Fig. 1(c)) also clearly shows the 100 percent alteration. This is confirmation for the image to be a stego-image

3.2 Stego-Sensitive Threshold Close Color Pair Signature

This method was proposed in ([18]). The colored images are represented as three channels of 8 bit each. In colored images, The LSB of any color channel contains least geometric information about the image contents and is most random in nature. The stegonography in a colored image is the technique of replacing the LSB of color channels by message bits.



(a) Cover image (b) Stego-image after 50 % embedding (c) Stego-image after 100 % embedding

Fig. 1. LSB bit plane of (a) cover image, (b) stego-image after 50 % embedding and (c) stego-image after 100 % embedding

The LSB substitution creates the randomness which causes change in number of Close Color Pair (CCP) and Unique Color (UC). The CCP and UC are calculated as:

Close Color Pair: The two colors pixels (r_1, g_1, b_1) and (r_2, g_2, b_2) are said to be similar if

$$| r_1 - r_2 |= 1, \text{ and } | g_1 - g_2 |= 1, \text{ and } | b_1 - b_2 |= 1$$

Alternatively, this measure can be represented as

$$(r_1 - r_2)^2 + (g_1 - g_2)^2 + (b_1 - b_2)^2 \leq 3$$

Unique Color: The two colors pixels (r_3, g_3, b_3) and (r_4, g_4, b_4) are unique Colors if

$$| r_3 - r_4 |= 1, \text{ or } | g_3 - g_4 |= 1 \text{ or } | b_3 - b_4 |= 1$$

The relevance of CCP and UC is defined as the ratio. The R is the ratio of CCP with unique colors UC of the original image.

$$R = \frac{CCP}{UC} \quad (0.1)$$

After the substitution the ratio $R^{'}$ will be computed as:

$$R^{'} = \frac{CCP^{'}}{UC^{'}} \quad (0.2)$$

Where $CCP^{'}$ and $UC^{'}$ are the close color pair and unique color of the stego-image and $R^{'} > R$ The percentage change PC in R given by:

$$PC = \frac{(R - R^{'}) \times 100}{R} \quad (0.3)$$

The threshold is calculated as

$$T = \frac{PC}{SSIM} \quad (0.4)$$

Where SSIM is the structural similarity index measure, this measure is defined in the next section. This measure captures the structure similarity of two images. The value of threshold T is different for original image and stego image which is a differentiating factor for original and embedded image. If $m < T$ then the image is stego-image.

3.3 RS Analysis

The RS was introduced first in ([19]). This analysis is based on the content of all bit planes of an image are correlated with the other bit plane. The 8 bit per pixel images have correlation between the LSB plane and the remaining bit planes. A message is substituted in the LSB plane, it creates randomness, as a result, the correlation between the LSB planes and other bit planes is decreased or lost. The RS steganalysis uses discrimination function f. This function is defined as the sum of all the distances between neighboring pixels. A flipping operation F to create grouping g of pixels. These grouping g are classifying into three categories depending on how the flipping operation F changes the value of the discrimination function f.

Regular Groups (RG): if $f(F(g)) > f(g)$ then $g \in RG$

Singular Groups (SG): if $f(F(g)) < f(g)$ then $g \in SG$

Unchanged Groups (UG): if $f(F(g)) = f(g)$ then $g \in UG$

$F(g)$ is the applying F on g. In original images, LSB flipping mask to the pixels in the group increases the discrimination function f and total number RG in an image will be larger than SG. But the randomness of the LSB plane after substitution makes the dissimilarity of RG and SG to zero, as the length of embedding message increases.

4. ANALYSIS TOOLS AND IMAGE QUALITY (ASSESSMENT

The Image Quality assessment methods([13]) in steganalysis are used in such a way that these IQM do not give the ideal results for the original and stego-image. These Important tools are used for comparison:

4.1 Histogram Measure

The pixel data is represented in a histogram. Each bin of the histogram represents the number of pixels which have the same gray level value. For the colored images, the histogram is calculated for each color separately and effect of institution is analyzed for each color.

4.2 Mean Square Error (MSE)

The MSE estimates the average square difference between the pixels of an image. Their mathematical definition is as follows:

$$MSE = \frac{1}{MN}\sum_{i=1}^{N}\sum_{j=1}^{M}[CI(i,j) - SI(i,j)]^2$$

Where $(N \times M)$ is the size of the reference and synthetic image. The cover image is represented by CI and SI stands for the stago image. Its result is always positive.

4.3 Peak Signal Noise Ratio (PSNR)

The PSNR It is inversely proportion to mean square error. Small value indicates poor image quality. Also it is SNR when the entire pixel's intensity value is same as of maximum.

$$PSNR = 10\log_{10}\frac{\max^2}{MSE}$$

Where $\max$ is the maximum pixel value. Its result is also positive.

4.4 Universal Image Quality Index (UIQI)

This measure was introduced in UIQI breaks the comparison between Cover Image (CI) and Stego-Image (SI) into three comparisons: luminance, Contrast and structural comparison. Mathematically these can be defined as:

$$Luminance(C_I, S_I) = L(C_I, S_I) = \frac{2\mu_{C_I}\mu_{S_I}}{\mu_{C_I}^2 + \mu_{S_I}^2} \tag{0.5}$$

$$Contrast(C_I, S_I) = \frac{2\delta_{C_I}\delta_{S_I} + C_2}{\delta_{C_I}^2 + \delta_{S_I}^2} \quad (0.6)$$

$$SI(C_I, S_I) = \frac{2\delta_{C_I}\delta_{S_I}}{\delta_{C_I} + \delta_{S_I}} \quad (0.7)$$

Where μ represents the arithmetic mean and δ is used for standard deviation and structural information is represented by si. Mathematically,

$$\mu_{CI} = \frac{\sum_{i=1}^{N} CI(i)}{N} \quad (0.8)$$

$$\mu_{SI} = \frac{\sum_{i=1}^{N} SI(i)}{N} \quad (0.9)$$

and

$$\delta_{CI}^2 = \frac{\sum_{i=1}^{N} (CI(i) - \mu_{CI})^2}{N-1} \quad (0.10)$$

$$\delta_{SI}^2 = \frac{\sum_{i=1}^{N} (SI(i) - \mu_{SI})^2}{N-1} \quad (0.11)$$

cross correlation is defined as

$$\delta_{CISI} = \frac{\sum_{i=1}^{N} (CI(i) \times SI(i))^2 - \sum_{i=1}^{N} CI(i) \times \sum_{i=1}^{N} \mu_{SI})^2}{N-1} \quad (0.12)$$

$$UIQI(C_I, S_I) = L(C_I, S_I) \times C(C_I, S_I) \times SI(C_I, S_I)$$

4.5 Structure Similarity Index Measure (SSIM)

The interconnected pixels have strong dependencies. The other similarity measures estimate perceived error, where as the SSIM estimates "Perceived change in structural information". It computes the similarity between two images of common size ([15]). Its mathematical definition is as:

$$SSIM(C_I, S_I) = \frac{(2\mu_{C_I} + \mu_{S_I} + C_1)(\delta_{C_I} + \delta_{S_I} + C_2)}{(\mu_{C_I}^2 + \mu_{S_I}^2 + C_1)(\delta_{C_I}^2 + \delta_{S_I}^2 + C_2)} \quad (0.13)$$

where μ, δ will be computed in the same way as in UIQI and C_1, C_2 are constants. These constants are defined as

$$C_1 = (K_1 L)^2, C_2 = (K_2 L)^2$$

where $K_1 = 0.01, K_2 = 0.03$ and $L = 2^{\#bitsperpexil} - 1$. The output of the SSIM measure is always in the same interval as UIQI. These measures are designed to improve MSE and PSNR. The UIQI and SSIM are more accurate and consistent than MSE and PSNR. All above image quality measure tools shows their ideal value when both original and modified images are identical.

5. EXPERIMENTAL RESULTS AND DISCUSSION

This section is concerned with the analysis of the substitution techniques at each bit of the image and their impact on the image quality.

5.1 Grayscale Images

This section is composed of two subsections. In the first subsection, we compare the visual impact of stagnography on gray image by histograms and in second subsection we compare the impact on the image by statistical measures. First of all, experiments are performed for the gray images. In the next example, we extend our results for the colored images.

5.1.1 Histogram analysis

In Fig. 2, the Fig. 2a is the original grayscale image, Fig. 2b is the histogram of the grayscale cover image. This histogram shows the minimum and maximum gray level pixel value respectively, present in cover image and number of pixels having same gray value. Visually, this histogram shows that the majority of pixels have the value in the range of $[100, 200]$. For the further analysis, this histogram will be compared with the histogram obtained after the bit alteration of gray image.

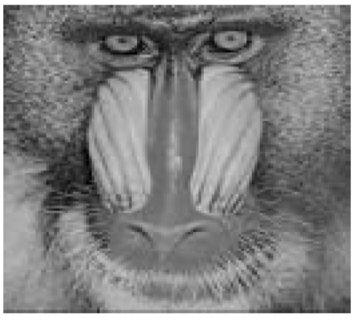
All the experimental results for gray scale images are shown after replacing all the pixels except the corner pixels of gray scale cover image.

In Figs. 3(a-h) are 1st to 8th bit grayscale stego-images respectively. In these images, the described bit is altered, for example, in Fig. (3a), first bit is changed. This change in the bit also changes the visual features of the image, as a result, its histogram also changed.

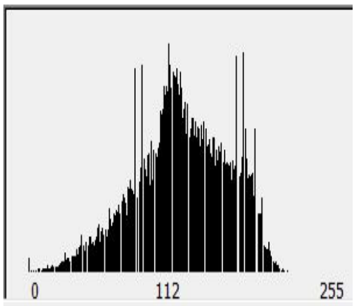
In Figs. 4 (a-h) are histograms of 1st to 8th bit gray scale stego-images respectively. In these histograms, the histogram is changed after the substation of massage bits. This substitution has the maximum effect for the substitution for the first bit and minimum effect for the substitution of 8th bit.

5.1.2 Statistical measurements

We compare the images after the substitution of each bit to the covered image with the statistical measures. The statistical results shows that the image quality is much better for the 4th bit or onward substitution. The statistical comparison is shown in the Table 1



(a) Cover Image

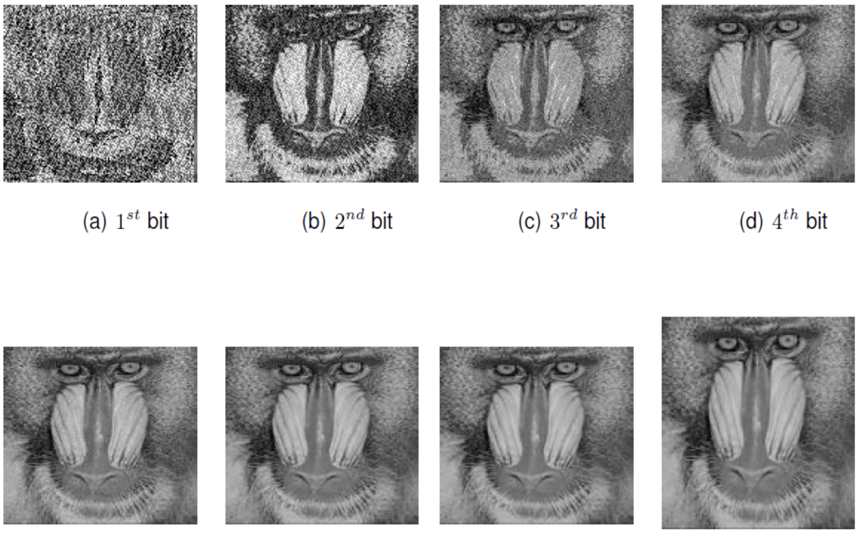


(b) Histogram of Cover Image

Fig. 2. Cover image and its histogram

Table 1. Experimental result of image quality measures for grey images

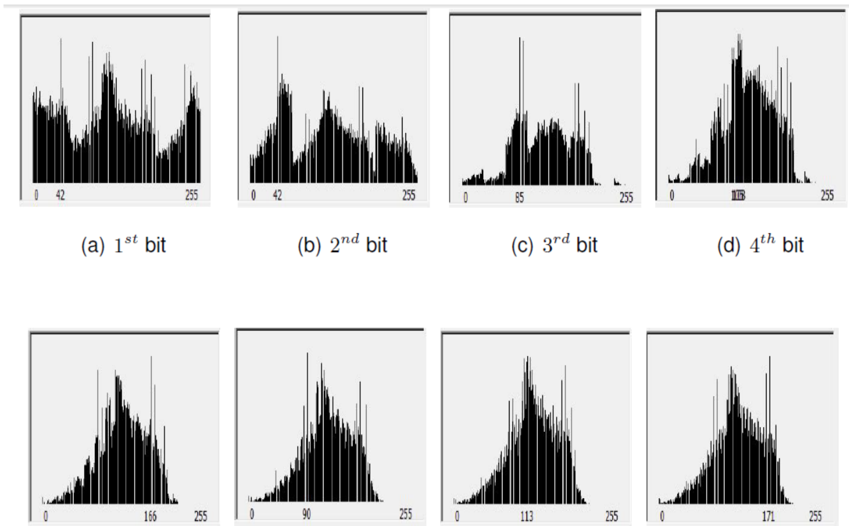
	MSE	PSNR	UIQI	SSIM
1^{st} BIT SI	7953.8878	7.3136	-0.1506	-0.1469
2^{nd} BIT SI	2048.2474	13.2056	0.6498	0.6518
3^{th} BIT SI	511.9887	19.2268	0.8358	0.8377
4^{th} BIT SI	126.5095	25.2982	0.9545	0.9551
5^{th} BIT SI	32.0829	31.2567	0.9881	0.9882
6^{th} BIT SI	7.7876	37.4053	0.9971	0.9971
7^{th} BIT SI	1.9215	43.4829	0.9993	0.9993
8^{th} BIT SI	0.5341	49.0428	0.9998	0.9998



(a) 1^{st} bit (b) 2^{nd} bit (c) 3^{rd} bit (d) 4^{th} bit

(e) 5^{th} bit (f) 6^{th} bit (g) 7^{th} bit (h) 8^{th} bit

Fig. 3. Stago images



(a) 1^{st} bit (b) 2^{nd} bit (c) 3^{rd} bit (d) 4^{th} bit

(e) 5^{th} bit (f) 6^{th} bit (g) 7^{th} bit (h) 8^{th} bit

Fig. 4. Stago image histograms

5.2 Colored Images

Histogram Fig. 5a is the original RGB cover image, the Fig. 5b is the histogram of the RGB cover image which is the mean of three channel based histograms. The Figs. (5(b-e)) are the channel based histogram of the RGB cover image. These histograms shows that the number of pixels for each level.

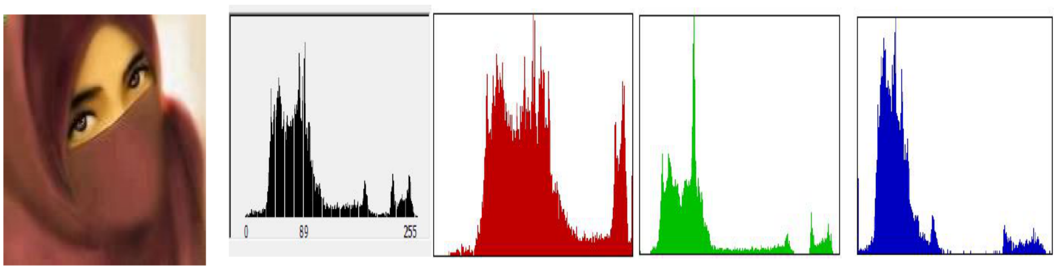
5.2.1 Histogram analysis

All the experimental results for RGB images are shown after replacing corresponding bits for each pixel of RGB cover image. In following Fig. 6a is the image obtained by replacing the pixels of the first bit. The Figs. (6(b-e) are the corresponding histograms. Visually the image changes and these changes are also reflected from the histograms. The rang of each histogram is changed.

In the Fig. 7(a), the second bit is replaced with the message bit, as a result, there appear many changes on the image. The histograms are represented in Figs. 7(b-e), these histograms are also changed. This change has the maximum effect for the red channel histogram.

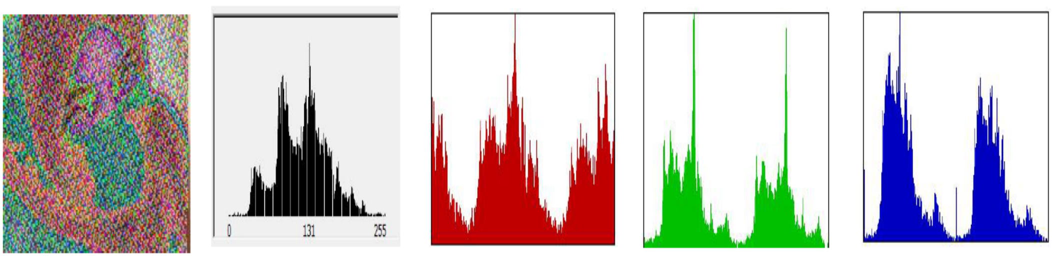
In the Fig. 8(a), the third bit is replaced with the message bit, as a result. The image is changed but these changes appear less effectively as compared to the previous substation. The histograms are represented in Figs. 8(b-e). There are minor changes in the mean histogram, but the channel based histograms are changed.

The Fig. 9(a) represents the change in forth bit of an image. This image seems to close only a small amount of noise appears in the image. Its mean histogram Figs. 9(b-e) is also close to the mean histogram of the original image, but its channel based histograms are effected and the changes are visible. The Fig. 10(a) represents the image after the replacement of fifth bit. This image seems to close only a small amount of noise appears in the image. Its mean histogram (Fig. 10(b)) is also close to the mean histogram of the original image. Its green channel histogram (Fig. 10(d)) is closer to the original green channel histogram but other channel based histograms are effected and the changes are visible. The image after the replacement of sixth bit (Fig. 11(a) is less effected and its mean histogram (Fig. 11(b) is also close to the mean histogram of the original image. The channel based histograms (Figs. 11(c-e) differ from the respective histograms of the original image in area or number of pixels having the same values.



(a) (b) (c) (d) (e)

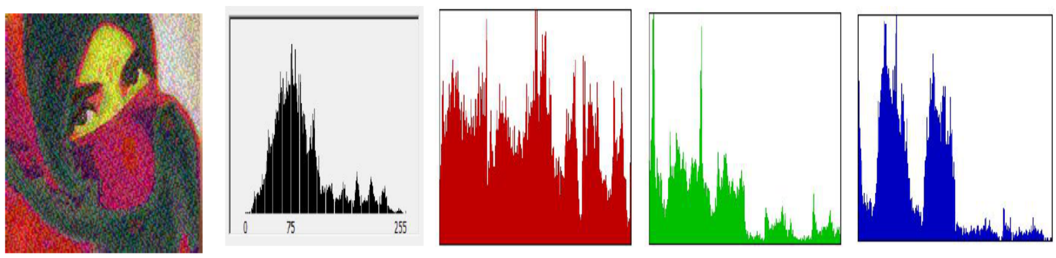
Fig. 5. Cover Image, mean and channel based histograms



(a) (b) (c) (d) (e)

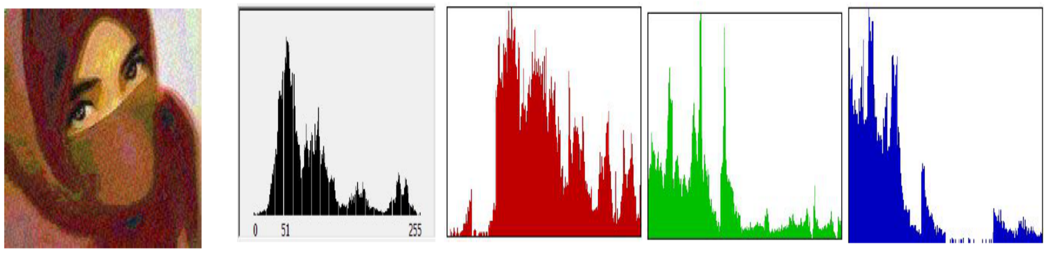
Fig. 6. First bit stag image and its histograms

In the seventh bit replacement of the image with the message bit, the image (Fig. 12(a) is similar to the original image only the color of the image becomes faint in some areas of the image. Its histograms (Figs. 12(b-e) are also closer to the histograms of the original image. The Fig. 13(a) represents the image after the replacement of 8^{th} bit with the message bit. This image seems to very close to the original image. Its mean histogram Fig. 13(b) is also close to the mean histogram of the original image and its channel based histograms (Figs. 13(c-e)) also reassembles with the channel based histograms.



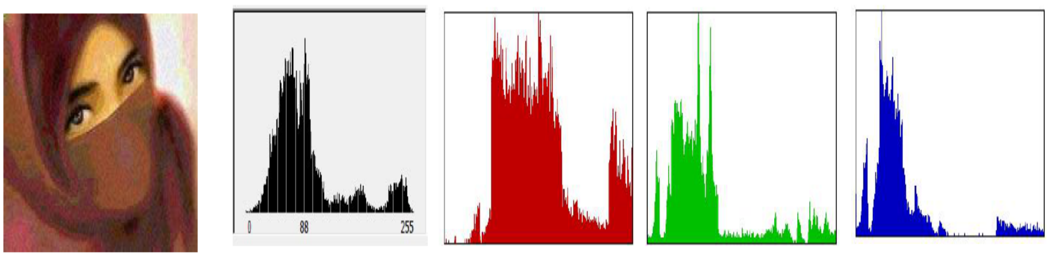
(a) (b) (c) (d) (e)

Fig. 7. Second bit stag image and its histograms



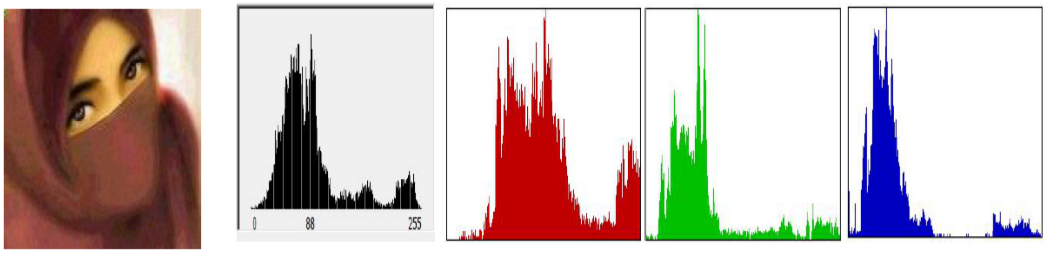
(a) (b) (c) (d) (e)

Fig. 8. Third bit stag image and its histograms



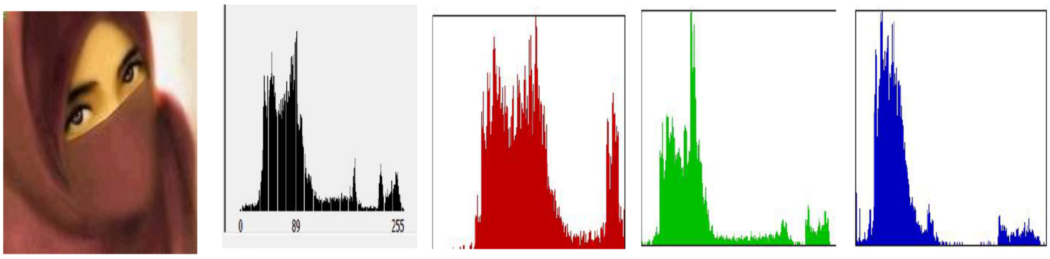
(a) (b) (c) (d) (e)

Fig. 9. Forth bit stag image and its histograms



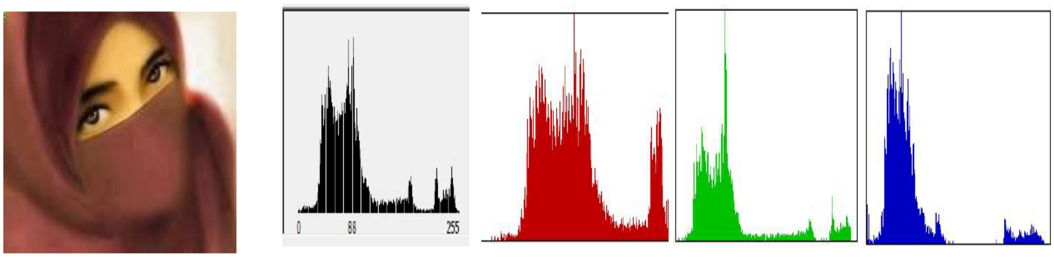
(a) (b) (c) (d) (e)

Fig. 10. Fifth bit stago image and its histograms



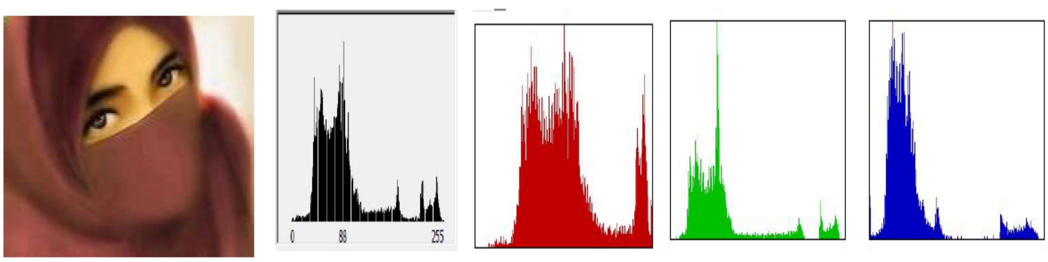
(a) (b) (c) (d) (e)

Fig. 11. Sixth bit stago image and its histograms



(a) (b) (c) (d) (e)

Fig. 12. Seventh bit stago image and its histograms



(a) (b) (c) (d) (e)

Fig. 13. Eighth bit stego image and its histograms

Table 2. Experimental result of image quality measures for colored images

	MSE	PSNR	UIQI	SSIM
1^{st} BIT SI	7663.4649	9.1924	0.1696	0.1671
2^{nd} BIT SI	1991.4469	15.0669	0.7123	0.7121
3^{th} BIT SI	510.9633	21.0838	0.9181	0.9182
4^{th} BIT SI	124.6382	27.1898	0.9792	0.9792
5^{th} BIT SI	31.5814	33.1538	0.9947	0.9947
6^{th} BIT SI	7.9052	39.1568	0.9987	0.9987
7^{th} BIT SI	1.9708	45.1771	0.9997	0.9997
8^{th} BIT SI	0.4919	51.1989	0.9999	0.9999

Table 3. Performance Using Hard Decision Detection

8^{th} BIT SI	Increment/Decrement by 1 or No change
7^{th} BIT SI	Increment/Decrement by 2 or No change
6^{th} BIT SI	Increment/Decrement by 4 or No change
5^{th} BIT SI	Increment/Decrement by 8 or No change
4^{th} BIT SI	Increment/Decrement by 16 or No change
3^{th} BIT SI	Increment/Decrement by 32 or No change
2^{nd} BIT SI	Increment/Decrement by 64 or No change
1^{st} BIT SI	Increment/Decrement by 128 or No change

5.2.2 Statistical measurements

The results for the statistical measures are represented in the following Table 2. The measures for the colored images are taken separately for each colore, then mean of each measure is considered. The greater the value of MSE and lesser PSNR means that perceived error is high. The UIQI and SSIM closer to 1 means that perceived change in structural information is very less and 1 means identical images. This table shows that, there is a comprehensive change when the message bits are subsituted into the 1^{st} bit of a pixel. This change becomes less effective as the subsitution bit moves from the first bit towards the LSB bit of a pixel.

5.3 Discussion

Visual appearance of stego-images in first four bits (from 1st bit to 4th bit) is very poor. The change in histogram is also at great extinct for those stego-images. However improvement occurs after 4th bit substution. The Table 3 shows the change in pixel value, which is minimum for 8th(LSB) bit and increases as move towards 1st bit.

All these results shows that data can be hidden only in the LSB of the pixel

6. CONCLUSIONS

Image LSB substitution Steganography for every bit of pixel is critically analysed and performance is measured by comparasion. The MSB of the image contain most important information, so change to that bit has the maximum effect on the image quality. This paper also compares important image quality assessment methods and discusses the attacks on the LSB method. From this analysis, one can develop a new better technique of image steganography and steganalysis.

COMPETING INTERESTS

The authors declare that no competing interests exist.

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The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/11856