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COMPARATIVE STUDY OF EDGE BASED LSB MATCHING STEGANOGRAPHY FOR COLOR IMAGES

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Abstract

Steganography is a very pivotal technique mainly used for covert transfer of information over a covert communication channel. This paper proposes a significant comparative study of the spatial LSB domain technique that focuses on sharper edges of the color as well as gray scale images for the purpose of data hiding and hides secret message first in sharper edge regions and then in smooth regions of the image. Message embedding depends on content of the image and message size. The experimental results illustrate that, for low embedding rate the method hides the message in sharp edges of cover image to get better stego image visualization quality. For high embedding rate, smooth regions and edges of the cover image are used for the purpose of data hiding. In this steganography method, color image and textured kind of image preserves better visual quality of stego image. The novelty of the comparative study is that, it helps to analyze the efficiency and performance of the method as it gives better results because it directly works on color images instead of converting to gray scale image

Keywords:

Information Hiding, Spatial Domain Image Steganography, Least Significant Bit (LSB), Edge Based LSB

1. INTRODUCTION

Today steganography has huge importance because of increasing use of internet and other new technologies. National, corporate, personal information security is an important concern. It is necessary to employ novel methods for confining the access to the data over a communication channel. Steganography has many applications in information hiding domain. In image steganography there are typically two categories: Spatial domain and the second one is called the transform domain. Spatial domain has methods that tend to operate on pixels directly. In spatial domain embedding steganography [1] algorithm is based on modification of the Least Significant Bit (LSB) layer of images. This technique primarily uses the fact that the LSBs in an image may be considered as of random noise and any alterations to them would not result in any significant or insignificant effect on the image. This phenomenon becomes evident by observing the image that is seemed to remain unchanged visually even after the alteration of LSB. It becomes clearly evident by examining noteworthy modifications in the image's statistical properties. The statistical changes may be used to detect Stego images. LSB method is used for creation of Stego images where the LSB of the pixels is replaced by the message that is to be sent. The permutation of message bits is done before embedding, that results in distribution of bits evenly. LSB embedding based popular steganography tools differ significantly in information hiding approach. In an effort to have more robust technique, of steganography, it is required to have security, satisfiable capacity, pivotal detection ability, peculiar robustness and visibility level against unintentional and malicious attacks [2]. In the spatial domain, lot of steganography methods are put forth, but the difficulty lies in providing better visualization quality in image steganography to maintain sharpness and maintain continuity across regions that are noisy.

2. LITERATURE SURVEY

This section reviews some of the works which have been done on image steganography, the most extensively used technique to hide data, with the usage of the LSB. Lossless compression format is mainly essential as each pixel bit existent in the image is used by this method. However, in case of transformations of lossy compression algorithm, information that is hidden tends to get lost. During usage of a color image of 24 bits, use of distinct bits of red, green and blue color components individually is done which results in storage of 3 bits in each pixel [3]. LSB replacement method involves a message to be embedded into the cover image and replacing the LSBs of the cover image with message bits. In the method pixel values are increased either by one or left unchanged, while odd values are decreased by unity or left unmodified. As a result, existence of an imbalance in the embedding distortion in the stego image is visible. Introduction of structural asymmetry reduces the difficulty to detect and identify the existence of hidden message. In this way LSB matching thereby tends to modify the cover image's LSBs for embedding of messages. LSB matching not only does replace the cover image's LSBs similar to that as LSB replacement does but also, random addition or subtraction of one is done, if there is mismatch between the message bit and LSB of the cover image from the cover pixel value [4]. This is edge based method so it provides good imperceptions ability to detect hidden message to human eye [5], [1]. This results to make the detection of the Edge Based LSB matching method harder than the ordinary LSB matching method [6]. Chan and Cheng (2003) [7] used the simple and easy to understand LSB Substitution method and put forth the data hiding concept in images by this method. The work uses optimal pixel adjustment process (OPAP) for the enhancement of the Stego image. It is applied on gray scale images in which 2-4 bits of the original cover image pixels are mainly used for the secret embedding of data bits. Sutaone and Khandare (2004) [4] have put forth in image Steganography the concept of random insertion LSB. Yang, Weng, Wang (2008) [1] put forth the new adaptive LSB technique that makes use of spatial LSB domain technique along with the Pixel Value Differencing (PVD) [2]. Kim, Jung and Yoo (2008) [3] propose Edge Based LSB matching, a new technique that makes use of lofty competence data hiding by making use of the LSB and PVD method of replacement. This method helps to calculate the divergence value amongst two consecutive pixels and replaces LSB of cover pixel with secret bit. If the divergence value is small (i.e. smooth areas) then the LSB substitution method is particularly used else PVD method is mainly used when the value is large (i.e. edge areas).

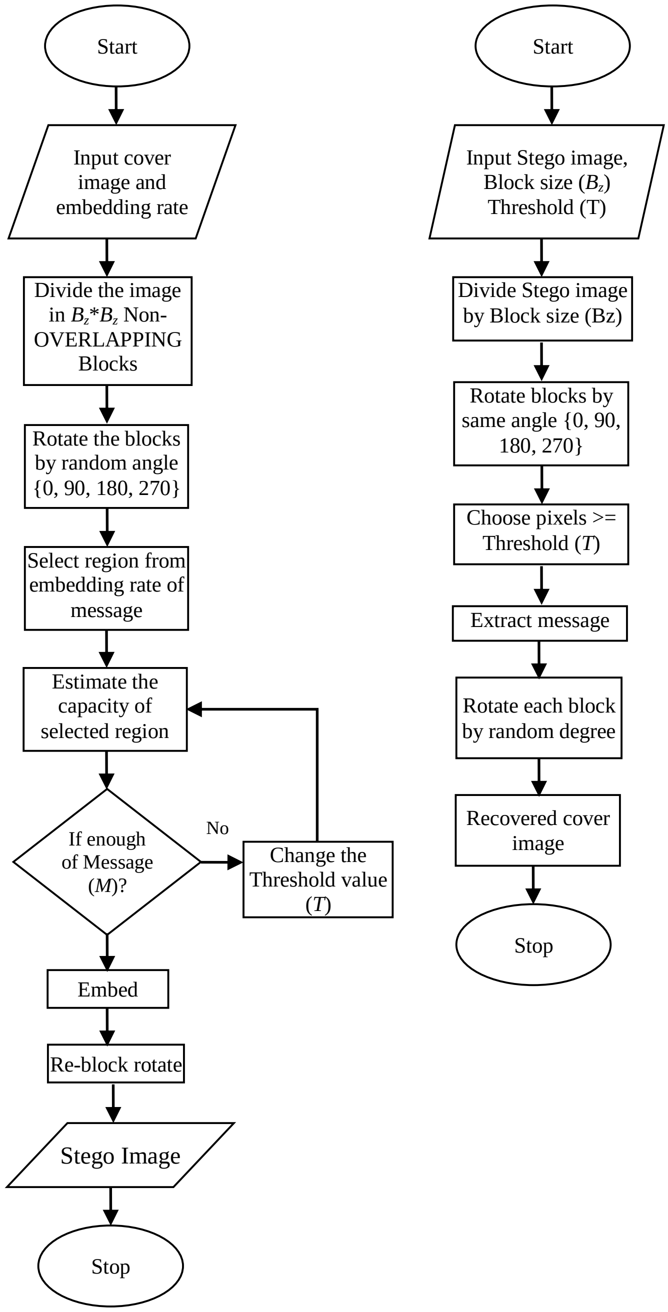
Wang and Moulin (2007) [8] put forth a three-level optimization of the classifier. Fridrich, Goljan and Du (2001) [9] for digital images describe a reliable and an accurate method for detection of the LSB with no sequential embedding Wu, Dumitrescu, and Wang (2003) [10] propose a modern, principled and a simple approach to detect the LSB steganography particularly in digital signals which include images and audio. Artz (2001) [11] puts forth digital steganography which particularly deals with inconspicuous hiding of data within data. Anderson and Fabien, Petitcolas (1998) [12] clarify the features of steganography. Zhang and Wang (2005) [13] proposes description of a universal steganalysis approach for identifying the presence of hidden messages embedded within digital images. Chan and Cheng (2004) [14] has reviewed the steganography method Edge Based LSB matching by Chang and Tseng (2004) and it describes the problem related to the Chang-Tseng scheme.

Fridrich, Goljan, Lisonek, and Soukal (2005) [15] propose an important information-theoretical model for a definite case of passive warden steganography. Fridrich and Soukal (2006) [16] put forth two new approaches for large payloads by matrix embedding. Jarno (2006) [17] has Edge Based LSB matching a revision to the matching of LSB's. Liu, Sung, Chen, and Xu (2008) [18] propose, Edge Based LSB matching a scheme that uses pattern classification and feature mining to detect LSB matching steganography in grayscale images.

Luo, Huang and Huang (2010) [4] Edge Based LSB matching method for grayscale images. The experimental work put forth in the paper was carried out on 6000 natural image dataset. The Edge Based LSB matching work is compared with Luo, Huang, Huang method [4], LSB Matching (LSBM), LSB Matching Revisited (LSBMR) [6], PVD [19], improved version of PVD (IPVD) [1], adaptive edges with LSB (AE-LSB) [20], and hiding behind corners (HBC) [21]. The visualization quality of stego image with peak signal-to-noise ratio (PSNR) value is mentioned in Table.3. The method put forth in this paper is an edge based LSB Matching for color images and gray scale images.

3. EDGE BASED LSB MATCHING WORK

The Fig.1(a) shows the flow of the Edge Based LSB matching method for data embedding process of both color images and gray scale images. For color image input chosen is only one particular channel red (R) or green (G) or blue (B) for embedding data. In the next succeeding step divide the image in non-overlapping blocks and rotate each one of block by random degree (0, 90, 180, 270). Then for embedding data, select region depending on size of secret message and image content itself. If selected region is not enough for data embedding then decrease threshold up to embedding capacity of message. Then perform embedding of the message in it and perform re-block rotate. The output obtained is the stego image.



(a) Embedding Process (b) Extraction Process

Fig.1. Flowchart of Edge Based LSB Matching Algorithm

The Fig.1(b) shows the flow of the Edge Based LSB matching method for data extraction. Stego image threshold (*T*), block size (B_z) is taken as input. The Extraction process is same as the embedding process but works in reverse order. Different secret message and image content have different parameters. For region selection we use the absolute difference that exists between two adjacent pixels. The detail steps are given in the algorithm as follows.

3.1 DATA EMBEDDING

Step 1: Color or gray scale image is taken as input. For color image of 24 bit, choose one bit plane RGB for embedding data.

Step 2: The cover image is initially divided into $B_z \times B_z$ non overlapping pixel blocks. Each of the small block, is then rotated by a random degree {0, 90, 180 and 270}. This rotation is performed in the range that is determined by a secret key. Then the rearrangement of the resulting image is carried out by raster scanning as a row vector V [5].

Step 3: The resultant matrix contains all the pixels of the cover image. There exist separate odd number and even number of pixels in two different matrixes. Pixel pairs of adjacent pixels of cover image are obtained.

Step 4: Use 2 LSB bits of each embedding unit to hide 2 secret bits. For color image use RGB bit plane for hiding the data in it. The threshold (T) can be determined from the secret message size and the total number of elements present in the set of embedding unit [5].

Then we calculate the T by,

$$T = \arg\max_t \{2 * |EU(t)| \geq |M|\} \tag{1}$$

where, t = {0, 1, 2 ,…, 63}, $|M|$ is the length of secret message M. $|EU(t)|$ be the total number of embedding units.

Step 5: Performing data hiding on the set of [5]

$$EU(T) = \{(x_i, x_{i+1}) \| x_i - x_{i+1}| \geq T, \forall (x_i, x_{i+1}) \in V\} \tag{2}$$

Data hiding is performed for each individual unit (x_i, x_{i+1}), according the following four cases.

Case#1:

$$LSB(x_i) = (m_i) \& f(x_i, x_{i+1}) = (m_{i+1})(x'_i, x'_{i+1}) = (x_i, x_{i+1});$$

Case#2:

$$LSB(x_i) = (m_i) \& f(x_i, x_{i+1}) = (m_{i+1})(x'_i, x'_{i+1}) = (x_i, x_{i+1}) + r;$$

Case#3:

$$LSB(x_i) = (m_i) \& f(x_i, x_{i+1}) = (m_{i+1})(x'_i, x'_{i+1}) = (x_i - 1, x_{i+1});$$

Case#4:

$$LSB(x_i) \neq (m_i) \& f(x_i, x_{i+1}) \neq (m_{i+1})(x'_i, x'_{i+1}) = (x_i + 1, x_{i+1});$$

And the function f given below is defined as follows,

$$f(a,b) = LSB\left(\left\lfloor \frac{a}{2} \right\rfloor\right) + b \tag{3}$$

The (m_i) and (m_{i+1}) denotes the two secret bits to be embedded. The 'r' denotes the random value in (-1, +1) and (m_i, m_{i+1}) denotes the pixel pair obtained after data hiding. If (x'_i) and (x'_{i+1}) be the out of range [0,255] or new difference may be less than threshold T. Then we need to readjust it as (x''_i, x''_{i+1}) by,

$$x''_i, x''_{i+1}) = \arg\min_{(e_1,e_2)} \left\{ |e_1 - e_2| + |e_2 - x_{i+1}| \left\| \begin{matrix} e_1 - x'_i + 4k_1, e_2 = x'_{i+1} + 2k_2, \\ |e_1 - e_2| \geq T, \\ 0 \leq e_1, e_2 \leq 255, \\ 0 \leq T \leq 63 \\ k_1, k_2 \in Z \end{matrix} \right\| \right\} \tag{4}$$

The final result obtained is $LSB(x''_i) = m_i$, $LSB(x''_i) = m_{i+1}$, where, $0 \leq (x''_i, x''_{i+1}) \leq 255$, $|x''_i - x''_{i+1}| \geq T$.

Step 6: After data hiding, we perform division of the resulting image into $B_z \times B_z$ non overlapping blocks. We then perform rotation of the blocks by a random number of degrees based on key 1. The process is analogous to Step 1 except that the random degrees are opposite.

3.2 DATA EXTRACTION

The data extraction process is the reverse process of data embedding process.

Step 1: Stego image is taken as input in which secret data is embedded.

Step 2: For extraction of secret data from stego image block size (B_z) and threshold (T) is required. Afterwards, exactly same process as Step1 of data embedding process is performed.

Step 3: Rotation key is used for the rotation of each block of the cover image by some specific random degree and travelling order.

Step 4: Divide the stego image in $B_z \times B_z$ blocks and then by using random degree, rotate each block by using the same secret key that is key 1.

Step 5: The resulting image rearranged as row vector scanning V'. Finally, the embedding unit is obtained by dividing V' into non-overlapping blocks consisting with two consecutive pixels.

4. RESULTS AND DISCUSSION

4.1 DATASETS

Two datasets are used for testing, gray test images dataset [2], [22], [23] is natural 8 bit gray scale images. RGB test images dataset [22] is natural 3×8 bit RGB color images. The 200 images are used for our method is of size 600×600 color and gray images. Another standard test image dataset [23] and standard test images are used for the experimentation shown in Table.1 and Table.2.

Table.1. Details of Non Linear Large Scale Problem Set [22] [23]

Embedding Rate	Carrier file (512×512)	Text message length (bits)	PSNR (dB)	*T*
10%	Baboon.bmp	26214	61.2442	29
	Lenagr.png	26214	61.5088	14
	Elaine.tiff	26214	61.2962	16
	Elaine1.jpg	26214	61.8132	16
	Boat.tiff	26214	62.0114	19
Average PSNR = 61.57476				
30%	Baboon.bmp	78642	56.4186	19
	Lenagr.png	78642	56.2600	4
	Elaine.tiff	78642	56.4468	8
	Elaine1.jpg	78642	56.9390	8

	Boat.tiff	78642	56.9458	8
Average PSNR = 56.60204				
50%	Baboon.bmp	131072	54.1517	9
	Lenagr.png	131072	54.0270	2
	Elaine.tiff	131072	54.1209	3
	Elaine1.jpg	131072	54.6907	4
	Boat.tiff	131072	54.6624	4
Average PSNR = 54.3305				

Table.2. Result for Gray Scale Images [22] [23]

Embedding Rate	**Carrier file (512×512)**	**Text message length (bits)**	**PSNR (dB)**	***T***
10%	Lena.bmp	26214	61.8790	15
	Drag.jpg	26214	61.8261	29
	Alpha.png	26214	61.9507	18
	Baboon.tiff	26214	62.1167	29
	House.tiff	26214	61.9336	21
Average PSNR = 61.9412				
30%	Lena.bmp	78642	56.8421	6
	Drag.jpg	78642	56.8832	7
	Alpha.png	78642	56.9098	5
	Baboon.tiff	78642	57.3222	19
	House.tiff	78642	57.0906	19
Average PSNR = 57.00958				
50%	Lena.bmp	131072	54.5375	3
	Drag.jpg	131072	54.0477	0
	Alpha.png	131072	54.4893	2
	Baboon.tiff	131072	55.0360	9
	House.tiff	131072	54.6201	2
Average PSNR = 54.54612				

4.2 EXPERIMENTAL RESULTS

This section highlights the effectiveness as well as the efficiency of the Edge Based LSB matching method compared with existing relevant methods by presenting some experimental results. The Table.1, shows the results for color image with varying embedding rate for various image formats keeping text message constant given embedding rate to images. In Table.1, it is observed that by varying embedding rate 10%, 30%, 50%, and so on, the visualization quality degrades. The PSNR value for all color image formats is ~62dB, ~57dB and ~55dB for 10%, 30% and 50% embedding rate respectively and *T* decreases with increasing embedding rate.

The Table.2, shows the results for gray scale images and helps to observe that the visualization quality degrades by changing the embedding rate by 10%, 30%, 50%, and so on. The PSNR value for all color image formats is ~61dB, ~56dB and ~54dB for 10%, 30% and 50% embedding rate respectively and *T* decreases with increasing embedding rate.

The Fig.2 shows the graph of 512×512 five different color images and gray images with average PSNR value and embedding rate. Variable file formats like tagged image file format (TIFF), bitmap image file (BMP), joint photographic experts group (JPG), portable network graphics (PNG) etc. can be used as input image which is color or gray scale. The Fig.2 graph shows that embedding rate increases with decrease in average PSNR value calculated from Eq.(5), Eq.(6). The graph is drawn from the contents of the Table.1 and Table.2.

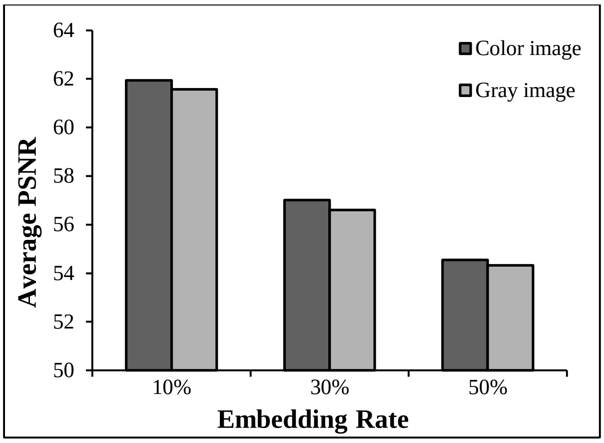


Fig.2. For same size and different format of Image with changing embedding rate

The PSNR is calculated for this method using following formula,

$$PSNR = 10\log_{10}\left[\frac{MAX_1^2}{MSE}\right] \tag{5}$$

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left[I(i,j) - K(i,j)\right]^2 \tag{6}$$

where, MAXI is mentioned as the maximum possible pixel value of cover image. MSE is Mean Square error.

$I(i, j)$ = Cover Image.

$K(i, j)$ = Stego Image

m = number of rows.

n = number of columns.

The Fig.2 shows that PSNR of color image is better as compared to the gray scale image. Thus, the method put forth in this paper is best for the color image for preserving higher stego image quality.

All type of texture images give us better performance. Image containing textures embeds a large amount of data and gives better PSNR value with maximum threshold value.

The Fig.3 shows the comparison of embedding rate vs. PSNR for the same dimension of color image and gray scale image. PSNR check is performed for the same dimension of color image and gray image with embedding rate 10%, 20%, …, 100%. Even here, the color image gives better performance. The value of PSNR falls between the ranges 50 dB to 63 dB.

After embedding message, the Fig.3 shows the difference between color and stego image. With embedding rate at 10%, data is embedded in only sharper edges of cover image. When embedding rate seems to increase, the more edge regions get released adaptive by decreasing *T* and PSNR value. It can also be observed that, when the embedding rate keeps low, most secret bits are hidden within the edge regions, thereby maintaining the smooth regions unmodified. Size of secret message thus helps to adjust the value of *T*. High PSNR is obtained for small message. For large message (embedding rate 100%) 1 bits per pixel (bpp) means all pixels of the cover image are used for embedding. In such cases, the Edge Based LSB matching method achieves maximum embedding capacity.

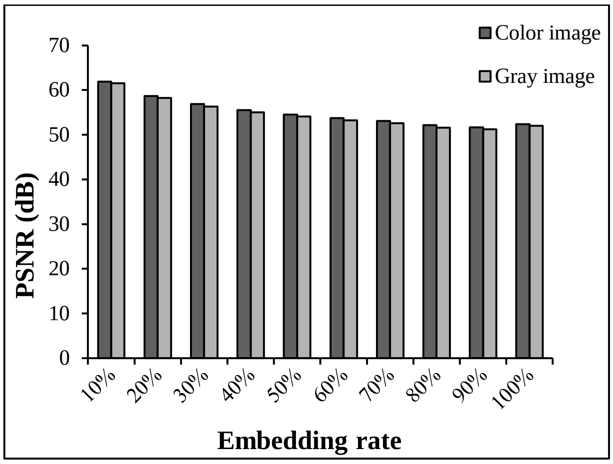


Fig.3. Comparison between color and gray 512×512 image changing embedding rate

4.3 COMPARISON WITH OTHER METHODS

Superiority of the new method is seen by observing the experimental results obtained using different kinds of steganalytic algorithms on natural images. The method compares with other methods like Luo, Huang, Huang method [5], LSBM [23], LSBMR [6], PVD [19], IPVD [1], AE-LSB [20], HBC [21]. From Table.3, comparison of embedding rate and average PSNR for color images and gray scale images for various methods is shown. The LSBM, LSBMR, PVD, AE-LSB, IPVD and HBC methods suit more likely for grays images stenography.

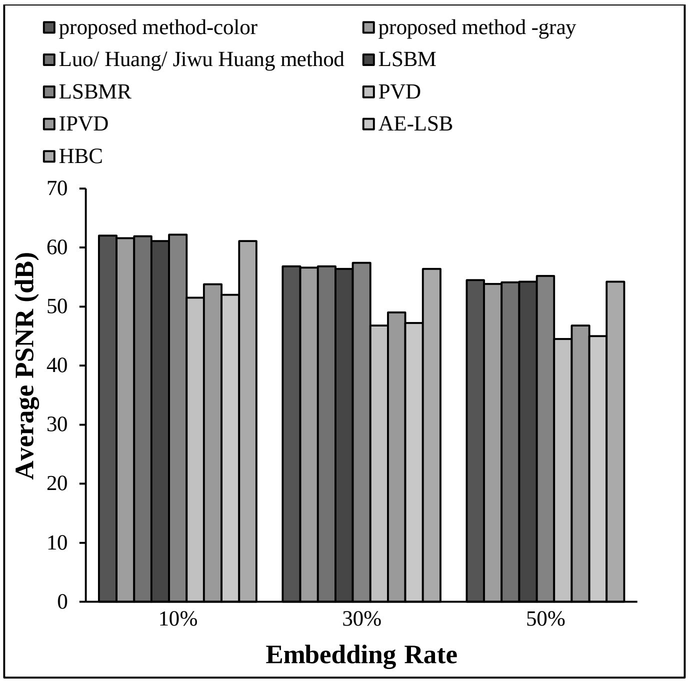


Fig.4. Comparison of Edge Based LSB matching method with other methods

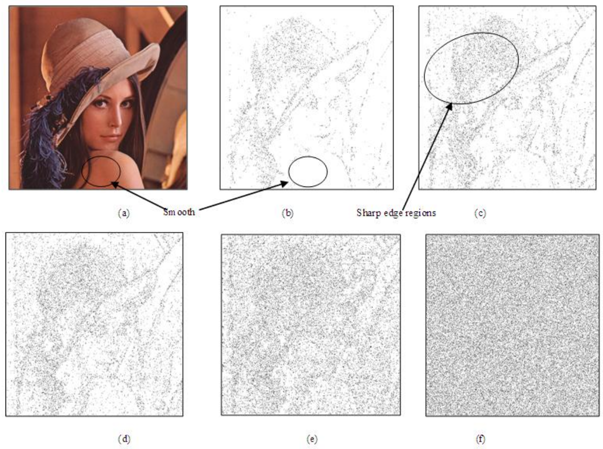


Fig.5. Difference between cover image and stego image (color)

Table.3. Comparison of Edge Based LSB matching method along with other methods

Methods / Embedding Rate	Edge Based LSB matching method-color images	Edge Based LSB matching method – gray images	Luo, Huang and Huang method [5]	LSBM [24]	LSBMR [6]	PVD [19]	IPVD [1]	AE-LSB [20]	HBC [21]
10%	62.04	61.58	61.90	61.10	62.20	51.50	53.80	52.00	61.10
30%	56.82	56.62	56.80	56.40	57.40	46.80	49.00	47.20	56.40
50%	54.49	53.86	54.10	54.20	55.20	44.50	46.80	45.00	54.20

Edge Based LSB matching method gives high stego image quality for color images compared with Luo, Huang and Huang method [5] and other methods except LSBMR [6]. The details are mentioned in Table.3.

The Fig.4 helps to show the comparison of the Edge Based LSB matching method along with other Edge Based LSB matching methods. In Table.3, Edge Based LSB matching method is divided into two separate categories color images and gray scale images. The Edge Based LSB matching method is beneficial for both color and gray scale images. For testing purpose we use 10%, 30%, 50% embedding rates.

The Fig.5(a) shows cover image (512×512 color image) input for our method. The difference between cover image and stego image is shown in Fig.5(b), Fig.5(c), Fig.5(d), Fig.5(e) and Fig.5(f). Black pixels show modified pixels after data hiding in cover image with embedding rate 10%, 20%, 30%, 50% and 100% respectively. The Fig.5(a) Cover image. (b) 10%, T = 15, PSNR = 61.8790. (c) 20%, T = 10, PSNR = 58.7665. (d) 30%, T = 6, PSNR = 56.8421. (e) 50%, T = 3, PSNR = 54.5375. (f) 100%, T = 0, PSNR = 52.3903.

The Fig.5 infers that the Edge Based LSB matching algorithm makes choice of only sharp edges of the image for embedding secret data and releases smooth regions present in the image. This is observed mainly for the lower embedding rate. It can be seen in Fig.5(b), Fig.5(c) and Fig.5(d) with 10%, 20%, 30% as the embedding rate respectively. At the time when embedding rate increases like 50% to 100% then use of smooth regions for embedding purpose is done. At 100% embedding rate use all the pixels of image for embedding data as displayed in Fig.5(f). The different images help to display how image is modified internally.

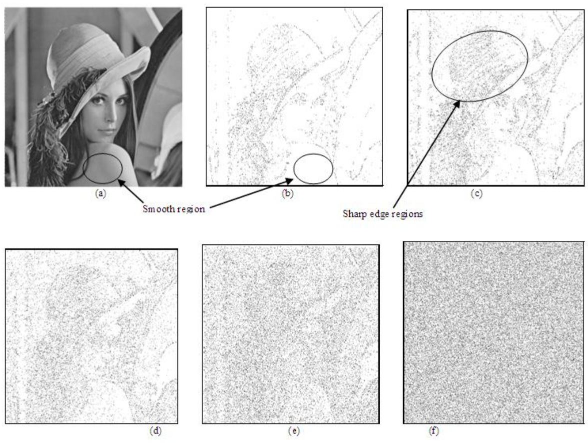


Fig.6. Difference between cover image and stego image (gray)

The Fig.6(a) shows cover image (512×512 gray scale image) as input. The difference between the cover image and stego image is shown in Fig.6(b), Fig.6(c), Fig.6(d), Fig.6(e) and Fig.6(f). In the cover image, the black pixels are modified after data hiding by 10%, 20%, 30%, 50% and 100% as embedding rate respectively. The Fig.6(a) Cover image (b) 10%, T = 12, PSNR = 61.4983. (c) 20%, T = 7, PSNR = 58.1679. (d) 30%, T = 4, PSNR = 56.2831. (e) 50%, T = 2, PSNR = 54.0243. (f) 100%, T = 0, PSNR = 52.0473.

The Fig.5 and Fig.6 helps to infer that for the lower embedding rate, it is observed that the Edge Based LSB matching algorithm makes choice of only sharp edges of the images for embedding secret data and releases smooth regions present in the images as seen in the Fig.5(b), Fig.5(c), Fig.5(d) and Fig.6(b), Fig.6(c), Fig.6(d) with embedding rate 10%, 20%, 30% respectively. When embedding rate increases like 50% to 100% then use smooth regions for purpose of embedding. We use all the pixels at 100% embedding rate of image for embedding of the data which is shown in Fig.5(f) and Fig.6(f). All the pixels of cover image are used for the embedding data. The difference in image shows how image is modified internally. The difference calculation between cover image and stego image is performed by subtracting stego image from the cover image. The Fig.5 and Fig.6 show the difference between color image (lena color.bmp) and gray scale image (lena gray.bmp) after embedding data. From the PSNR value and by observing the difference among color images and gray scale images, it is clear that stego color image preserves high visual quality than the stego gray image.

5. CONCLUSION

This paper presents, a comparative study of edge based LSB matching method based on spatial LSB domain steganography for color images. The study gives better results and provides analysis that the performance of the method is better as the method embeds small size data in edge areas of images and large size data in edges and smooth areas of the cover image. It also helps to derive the inference that this method preserves relatively higher stego image quality and provides better security by dividing the cover image in random block size and rotation of each block by random degree. In Future research, the comparative study of this method can be extended on different steganography techniques like video steganography, level of visibility, detection ability and robustness against different malicious attacks and various unintentional attacks. The Future research of this comparative analysis can also be extended to study the effect of data hiding in terms of visual image quality and to study edge distortions to formulate ways to overcome them, as they are significant image quality issues in many areas.

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REFERENCES

[1] Cheng-Hsing Yang, Chi-Yao Weng, Shiuh-Jeng Wang and Hung-Min Sun, "Adaptive Data Hiding in Edge Areas of Images with Spatial LSB Domain Systems", *IEEE Transactions on Information Forensics and Security*, Vol. 3, No. 3, pp. 488-497, 2008.

[2] Weiqi Luo, Fangjun Huang and Jiwu Huang, "A more Secure Steganography based on Adaptive Pixel-value Differencing Scheme", *Multimedia Tools and Applications*, Vol. 52, No. 2-3, pp. 407-430, 2011.

[3] Ki-Jong Kim, Ki-Hyun Jung and Yoo Kee-Young, "A High Capacity Data Hiding Method using PVD and LSB", *Proceedings of International Conference on Computer*

Science and Software Engineering, Vol. 3, pp. 876-879, 2008.

[4] M.S. Sutaone and M.V. Khandare, "Image based Steganography using LSB Insertion Technique", *Proceedings of IET International Conference on Wireless, Mobile and Multimedia Networks*, pp. 146-151, 2008.

[5] Weiqi Luo, Fangjun Huang and Jiwu Huang, "Edge Adaptive Image Steganography Based on LSB Matching Revisited", *IEEE Transactions on Information Forensics and Security*, Vol. 5, No. 2, pp. 201-124, 2010.

[6] J. Mielikainenm, "LSB Matching Revisited", *IEEE Signal Processing Letters*, Vol. 13, No. 5, pp. 285-287, 2006.

[7] Chi-Kwong Chan and L.M. Cheng, "Hiding Data in Images in Simple LSB Substitution", *Pattern Recognition*, Vol. 37, No. 3, pp. 469-474, 2004.

[8] Ying Wang and Pierre Moulin, "Optimized Feature Extraction for Learning-Based Image Steganalysis", *IEEE Transactions on Information Forensics Security*, Vol. 2, No. 1, pp. 31-45, 2007.

[9] J. Fridrich, M. Goljan and Rui Du, "Detecting LSB Steganography in Color, and Gray-Scale Images", *IEEE Multimedia*, Vol. 8, No. 4, pp. 22-28, 2001.

[10] S. Dumitrescu, X. Wu and Z. Wang, "Detection of LSB Steganography via Sample Pair Analysis", *IEEE Transaction on Signal Processing*, Vol. 51, No. 7, pp. 1995-2007, 2003.

[11] D. Artz, "Digital Steganographic: Hiding Data within Data", *IEEE Internet Computing*, Vol. 5, No. 3, pp. 75-80, 2001.

[12] R.J. Anderson and F.A.P. Petitcolas, "On the Limits of Steganography", *IEEE Journal on Selected Areas in Communications*, Vol. 16, No. 4, pp. 474-481, 1998.

[13] Xinpeng Zhang and Shuozhong Wang "Steganography using Multiple-Base Notational System and Human Vision Sensitivity", *IEEE Signal Processing Letters*, Vol. 12, No. 1, pp. 67-70, 2005.

[14] Chi-Kwong Chan and L.M. Cheng, "Hiding Data in Images by Simple LSB Substitution", *Pattern Recognition*, Vol. 37, No. 3, pp. 469-474, 2004.

[15] J. Fridrich, M. Goljan, P. Lisonek and D. Soukal, "Writing on Wet Paper", *IEEE Transactions on Signal Processing*, Vol. 53, No. 10, pp. 3923-3935, 2005.

[16] J. Fridrich and D. Soukal, "Matrix Embedding for Large Payload", *IEEE Transactions on Information Forensics and Security*, Vol. 1, No. 3, pp. 390-394, 2006.

[17] Jarno Mielikainen, "LSB Matching Revisited", *IEEE Signal Processing Letters*, Vol. 13, No. 5, pp. 285-287, 2006.

[18] Q. Liu, Andrew, H. Sung, Z. Chen and J. Xu "Feature Mining and Pattern Classification for Steganalysis of LSB Matching Steganography in Grayscale Images", *Pattern Recognition*, Vol. 41, No. 1, pp. 56-66, 2008.

[19] Da-Chun Wu and Wen-Hsiang Tsai, "A Steganographic Method for Images by Pixel-Value Differencing", *Pattern Recognition Letters*, Vol. 24, No. 9-10, pp. 1613-1626, 2003.

[20] Kh. Manglem Singh, L. Shyamsudar Singh, A. Buboo Singh and Kh. Subhabati Devi, "Hiding Secret Message in Edges of the Image", *Proceedings of. International Conference on Information and Communication Technology*, pp. 238-241, 2007.

[21] Kathryn Hempstalk, "Hiding behind Corners: Using Edges in Images for Better Steganography", *Proceedings on Computing Women's Congress*, 2006.

[22] Images dataset: Available at: http://testimages.tecnick.com.

[23] Images dataset: Available at: http://decsai.ugr.es/cvg/index2.php.