Image Steganography using Combined Nearest and Farthest Neighbors Methods

Farhana Sharmin[1], Muhammad Ibrahim Khan[2]
Department of Computer Science and Engineering
Chittagong University of Engineering and Technology, Chattogram, Bangladesh

***Abstract*—Security is invariably a significant concern during communication. With the ease of communication, there is always a pending threat of intrusion. Steganography is one such way to achieve security by concealing confidential information within a more innocent looking media like image, audio, video etc. In this paper, a new technique is proposed that uses the relationship of a pixel with its Nearest Neighbor and Farthest Neighbor to hide secret information into that pixel. The cover image is divided into2x2 non-overlapping blocks. According to the vulnerability of the relationship among the pixels, blocks are labelled as Stable and Unstable. The Stable block hides 'k' secret while unstable block hides 'n' secret bits. 25 types of different set of 'k' and 'n' is examined to evaluate the performance of proposed method. 2k method is applied to improve the quality of stego image. The experimental result shows that the proposed technique hides a significant number of secret bits with high PSNR. While compared with other existing methods, the proposed method achieves a much higher visual quality than that of those methods.**

Keywords—Steganography; cryptography; Pixel Value Difference (PVD); image processing; cover image; information security; stego image

I. Introduction

With the progress made in digital technology, information in analog form are being rapidly converted into their digital counterparts. Digital technology and the Internet today offer available cover medias for use in steganography. The frequency of digital image on the Internet makes it the most common option among different cover medias. Internet technology has bridged the global distance between people and organizations by allowing for fast and cheap communication. In areas such as online intellectual property rights, criminal, political and commercial communications there is always a fear of third-party intruder who is seeking access to our communication. It is not enough to rely upon the assumption that communications in today's high-tech world are safe and not being intercepted. Ensuring secure communication is essential. Different tools ensuring secure communication include: hiding the content or nature of communication (encryption, water-marking, steganography), hiding the parties to a communication (anonymity) and conceal a communication that has been taken place (obscurity). A perfect Steganographic system is however an ideal concept. Research in this field aims at increasing capacity, security and robustness of the system. Steganography is a mechanism that implants a secret message into unspectacular cover media to prevent arousing the suspicion of an eavesdropper. The cover media thus serves as a container for the secret information. The outcome is a stego media that appears indistinguishable from the original media and becomes undetectable. In the modern world digital steganography is used for secret communication as well as authentication. A steganographic system consists of two major parts: cover media and stego media. The confidential information that needs to be hidden is embedded in seemingly harmless media. This is the cover media. The result is a stego media that appears identical to the original cover media. Steganography hides information by altering certain characteristics of the cover media that cannot be detected by visual inspection. It makes use of both redundancies that exists in the digital cover media as well as the limitations of the human eye. The design goal of proposed technique is: larger payload and higher PSNR without compromising security.

II. Literature Review

Different types of steganographic techniques are proposed to serve different purposes. Original Pixel Value Differencing (PVD) method for gray scale image was proposed by Wu and Tsai in 2003 [1]. Here the cover image is segmented into non-overlapping blocks consisting two consecutive pixels. The difference values between the pixels are classified into ranges. Based on human vision's tolerance to gray value fluctuation, the interval of 'Range' is decided. Width of the ranges decides the number of secret bits to be hidden in a pixel. Thus, it is an adaptive method. To minimize the exposure of hiding effect of PVD method, Modulus Function (MF) is employed in [2]. In [3], turnover policy and novel adjusting process is employed to improve the performance of method proposed in [2]. Capacity promoting technique is proposed in [4] to increase hiding capacity by finding more edge areas. A new quantization range table, in [5], is designed on the basis of the perfect square number to achieve better image quality and higher capacity. By redefining the remainder function to a more general form, in [6], an indeterminate equation is derived to reduce image distortion. In [7], another steganographic technique is offered by using pixel value differencing on colour images which also ensures that no pixel value in stego image exceeds the range 0 to 255. Where pixel value does not cross the range, the original PVD method is used and elsewhere proposed method has been used for embedding data. Instead of focusing on individual color component, three color components are constituted into two overlapping blocks in [8], where PVD technique is used separately on each block to conceal secret data. In [9], two steganographic technique is proposed based on adaptive quantization range. In first technique, image is divided into 2x2 non overlapping pixel blocks and second technique divides the image into 3x3 overlapping pixel blocks. First technique offers higher capacity where higher PSNR is achieved by using the second technique which in consequence offers higher security. Smart pixel-adjustment technique is proposed in [10] to reduce visual distortion. Simple LSB substitution method [11] also achieves great image quality by applying Optimal Pixel Adjustment Process (OPAP). To provide greater embedding capacity and less manipulation of image, the side match method [12] exploits correlation between neighboring pixels. It hides secret data depending on the degree of smoothness. Pixel Value Modification (PVM) method [13] uses modulus function to embed secret information in a color image. Combined Pixel Value Differencing and Pixel Indicator Technique [14] is proposed to ensure higher security. Here one channel acts as an indicator where other two channels hold the secret information. Just Noticeable Difference (JND) technique and method of Contrast Sensitivity Function (CSF) is used in [15]. It is an edge detection method that utilizes partial information (3 bits from MSB) of each pixel value. The authors proposed a mathematical method, named 2k correction, for better imperceptibility. Author in [16] proposed the modified least significanr bits and modulus function with pixel value differencing techniques. Both steganography and cryptography is used in [17] for improved security. A higher quality form of the cover object is utilized in [18]. Author in [19] employed technique based on LSB manipulation and inclusion of redundant noise.

III. Proposed Method

The proposed method can be applied both on gray image and color image. In case of color image, the Red, Green and Blue channels are separated first. Then embedding and extraction algorithm is repeated on all three channels separately. Gray image does not need any pre-processing.

A. Embedding Process

Step 1: Divide the cover image into 2X2 non-overlapping blocks consisting four pixels: P_1, P_2, P_3 and P_4 as shown in Fig. 1.

P_1	P_2
P_3	P_4

Fig. 1. Cover Image Block.

Step 2: Calculate the distance of P_1 with its other neighbor pixels P_2, P_3 and P_4 by taking the differences as follows:

Difference between P1 and P2 = D1 = |P1 – P2|

Difference between P1 and P3 = D2 = |P1 – P3|

Difference between P1 and P4 = D3 = |P1 – P4|

Step 3: Determine the Nearest Neighbor (NN) and Farthest Neighbor (FN) of P_1. Compare D_1, D_2 and D_3 calculated in Step 2. The pixel that has the lowest distance from P_1 is called its Nearest Neighbor and the pixel that has the highest distance from P_1 is called its Farthest Neighbor. If D_i is the lowest distance then P_{i+1} is the nearest neighbor and If D_i is the highest distance then P_{i+1} is the farthest neighbor, where i = 1, 2, 3.

Step 4: Determine the Range of P_1 according to the following four relationship conditions:

Condition 1: If $NN > P_1 < FN$ then

Range = $[0, min\ (NN - 1, FN - 1)]$

Condition 2: If $NN < P_1 > FN$ then

Range = $[max\ (NN + 1, FN + 1), 255]$

Condition 3: If $NN \geq P_1 \geq FN$ then

Range = $[FN + 1, NN - 1]$

Condition 4: If $NN \leq P_1 \leq FN$ then

Range = $[NN + 1, FN - 1]$

Step 5: Calculate,

|Range| = upper limit – lower limit + 1

Step 6: Calculate the number of secret bits, n, to be hidden into P_1.

$n = \min(\text{floor}(\log_2(|Range|)), k)$

where ‘**k**’ may vary from 1 to 5. During experiment it is found that the method reaches the maximum capacity at k = 5.

Step 7: Take ‘n’ secret bits from the secret bit stream and convert into its decimal value ‘b’.

Step 8: Modify the value of pixel P_1:

$P_1' = P_1 - (P_1 \bmod 2^n) + b$

Step 9: To keep the new pixel value P_1' nearest to P_1, 2k Correction method is applied. The steps are as follows:

Step 9.1: If $|P_1' - P_1| > 2^{n-1}$ then go to Step 9.2. Otherwise P_1' remains unchanged.

Step 9.2: If $(P_1' - P_1) > 0$, then $P_1'' = P_1' - 2^n$ else $P_1'' = P_1' + 2^n$

Step 10: Check the stability of the relationship among the pixels in the block using Step 2 to Step 4. For correct message extraction, it is required to preserve the same relationship condition it has among the pixels even after hiding secret data. If the relationship among the pixels remains unchanged then the block is labelled as Stable Block and P_1'' remains unchanged. Otherwise the block is labelled as Unstable Block. In Unstable Block, all four pixels hide ‘n’ secret data. ‘n’ may vary from 1 to 5. For n>5, though the hiding capacity increases significantly but PSNR also drops drastically, which leads to vulnerability of the method. For this reason, the value of ‘n’ is limited from 1 to 5. After hiding n bits, P_1, P_2, P_3 and P_4 will be changed to P_1', P_2', P_3' and P_4' as follows:

$P_1' = P_1 - (P_1 \bmod 2^n) + b_1$

$P_2' = P_2 - (P_2 \bmod 2^n) + b_2$

$P_3' = P_3 - (P_3 \bmod 2^n) + b_3$

$P_4' = P_4 - (P_4 \bmod 2^n) + b_4$

Where, n is the secret binary bits and b_1, b_2, b_3 and b_4 are corresponding decimal values of those secret bits.

To increase security, secret information is embedded in random fashion. Secret message is embedded into stable blocks first then into unstable blocks. In that way, message is hidden in random order instead of sequential order.

For example, in Fig. 2, if 'abcdefghijklmnop' is the secret message, then it is embedded as 'jabkcdlemfgnohpi'. After embedding into all blocks of the cover image, we get the stego image.

B. Extraction Process

Step 1: Divide the stego image into 2X2 non overlapping blocks and identify stable blocks (Fig. 3) and unstable blocks (Fig. 4).

In case of stable blocks:

Step 2: Calculate the distance of P_1' with P_2, P_3 and P_4.

Difference between P_1' and P_2 = $D_1' = |P_1' - P_2|$

Difference between P_1' and P_3 = $D_2' = |P_1' - P_3|$

Difference between P_1' and P_4 = $D_3' = |P_1' - P_4|$

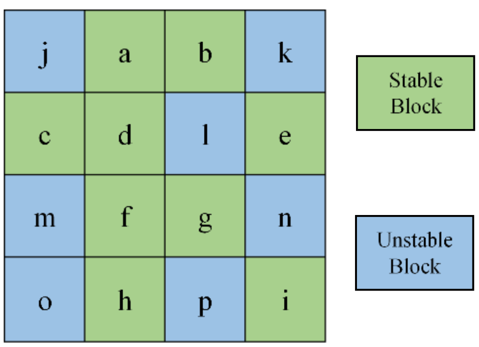

Fig. 2. Embedding Secret Message in Random Order.

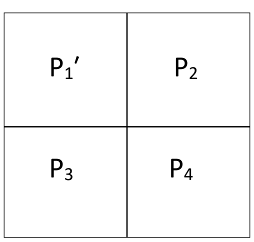

Fig. 3. Stable Block.

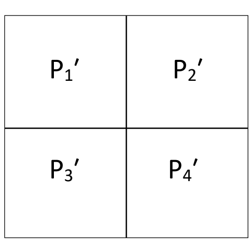

Fig. 4. Unstable Block.

Step 3: Determine the Nearest Neighbor (NN) and Farthest Neighbor (FN) of P_1' same as described in Step 3 of embedding process.

Step 4: Determine the Range of P_1' according to the four relationship conditions specified in Step 4 of embedding process.

Step 5: Calculate, $|Range| = upper\ limit - lower\ limit + 1$

Step 6: Calculate the number of secret bits 'n' to be extracted from P_1'.

$n = \min(\text{floor}(\log_2(|\text{Range}|)), k)$

Step 7: Extract **n** secret bits from the stego pixel P_1'.

$b = P_1' \bmod 2^n$

Step 8: Convert the decimal value b into its corresponding binary value. Obtained binary bits are the secret bits.

In case of Unstable Block, secret message is extracted from all four pixels using following equations:

$$PSNR = 10\log_{10}\left(\frac{MAX\ I^2}{MSE}\right)$$

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

$b_1 = P_1' \bmod 2^n$

$b_2 = P_2' \bmod 2^n$

$b_3 = P_3' \bmod 2^n$

$b_4 = P_4' \bmod 2^n$

By converting b_1, b_2, b_3 and b_4 into their corresponding binary value, we get the secret bits hidden into the pixels.

IV. Experimental Results

Most widely used 512X512X3 color images (Lena, Baboon, Pepper, Jet, Sailboat, House, Splash, Tiffany etc.) and 512X512 gray images (Lena, Boat, Baboon, Tank, Pepper, Tiffany, Jet, Elaine, Barbara, etc.) are used to conceal the secret information. In order to assess the efficiency of proposed method, two parameters are employed: Capacity and Peak Signal to Noise Ratio (PSNR). Capacity is the maximum number of secret bits an image can hide. Peak Signal to Noise Ratio (PSNR) quantifies the quality of stego image.

Here, MSE calculates the Mean Squared Error. I and K are cover and stego image respectively where both have m rows and n columns, c is the number of channels of the image. MAX_I is the maximum pixel value of cover image. Higher PSNR indicates better image quality. Usually, when the PSNR is greater than 30 dB, Human Visual System (HVS) is unable to detect the changes made in an image [20].

In steganography, capacity and PSNR walk in reverse way. The more the capacity, usually the lower is the PSNR. Lower PSNR leads to vulnerability of a method. In our proposed method, 'k' and 'n' play a major role to control the capacity.

As for example, Table I (color image) and Table II (gray image) depict how capacity (in bits) as well as PSNR (in db) varies for different values of '**k**' and '**n**' for image Lena. Users can choose any set of (k,n) to meet their priority requirement.

Taking 30 db as the threshold level PSNR, Table III and Table IV depicts the highest capacity with threshold level PSNR and capacity with highest PSNR for color images and gray images respectively. Capacity is measured in bits and PSNR is measured in db. From the experimental results, we can see that the proposed method can hide a large amount of secret information yet keeping a high PSNR.

Fig. 5 shows some color images and their corresponding stego images where some gray images and their respective stego images are shown in Fig. 6. However, it is also clear from the figures that it is evident that Human Visual System (HVS) does not perceive distortion.

TABLE. I. CAPACITY AND PSNR OF COLOR IMAGE LENA FOR DIFFERENT VALUES OF 'K' AND 'N'

Type of (k,n)	**Capacity**	**PSNR**
Type 1 (1,1)	742866	56.20
Type 2 (1,2)	1471202	51.45
Type 3 (1,3)	2199538	45.83
Type 4 (1,4)	2927874	39.85
Type 5 (1,5)	3470530	34.13
Type 6 (2,1)	712671	56.40
Type 7 (2,2)	1380255	51.76
Type 8 (2,3)	2047839	46.18
Type 9 (2,4)	2715423	40.22
Type 10 (2,5)	3381967	34.28
Type 11 (3,1)	702121	56.23
Type 12 (3,2)	1326941	51.88
Type 13 (3,3)	1951761	46.42
Type 14 (3,4)	2576581	40.50
Type 15 (3,5)	3201401	34.57
Type 16 (4,1)	702444	50.43
Type 17 (4,2)	1058920	49.44
Type 18 (4,3)	1415396	46.83
Type 19 (4,4)	1771872	42.29
Type 20 (4,5)	2128348	36.83
Type 21 (5,1)	702612	55.46
Type 22 (5,2)	1303484	51.69
Type 23 (5,3)	1904356	46.48
Type 24 (5,4)	2505228	40.63
Type 25 (5,5)	3106100	34.73

TABLE. II. CAPACITY AND PSNR OF GRAY IMAGE LENA FOR DIFFERENT VALUES OF 'K' AND 'N'

Type of (k,n)	**Capacity**	**PSNR**
Type 1 (1,1)	242106	51.55
Type 2 (1,2)	477530	46.82
Type 3 (1,3)	712954	41.19
Type 4 (1,4)	948378	35.22
Type 5 (1,5)	1158682	29.39
Type 6 (2,1)	232365	51.74
Type 7 (2,2)	448009	47.11
Type 8 (2,3)	663653	41.55
Type 9 (2,4)	879297	35.60
Type 10 (2,5)	1094941	29.68
Type 11 (3,1)	229963	51.65
Type 12 (3,2)	435735	47.22
Type 13 (3,3)	641507	41.73
Type 14 (3,4)	847279	35.79
Type 15 (3,5)	1053051	29.89
Type 16 (4,1)	230056	45.95
Type 17 (4,2)	351460	44.87
Type 18 (4,3)	472864	42.13
Type 19 (4,4)	594268	37.51
Type 20 (4,5)	715672	32.03
Type 21 (5,1)	229831	51.26
Type 22 (5,2)	430735	47.12
Type 23 (5,3)	631639	41.78
Type 24 (5,4)	832543	35.89
Type 25 (5,5)	1033447	29.98

TABLE. III. CAPACITY AND PSNR FOR PROPOSED METHOD (COLOR IMAGE)

Cover Image (512 x 512 x 3)	**Highest Capacity with threshold level PSNR**		**Capacity with highest PSNR**	
	Capacity	***PSNR***	***Capacity***	***PSNR***
Lena	3470530	34.13	712671	56.40
Baboon	3490302	34.14	768667	56.03
Pepper	3474527	34.28	730659	56.25
Sailboat	3481380	34.18	745340	56.17
Car house	3475411	34.19	708470	56.46
Splash	3321788	34.21	669662	56.75
Jet	3424467	34.33	684031	56.64
Tiffany	3471557	34.64	710055	56.40

TABLE. IV. CAPACITY AND PSNR FOR PROPOSED METHOD (GRAY IMAGE)

Cover Image (512 x 512)	Highest Capacity with threshold level PSNR		Capacity with highest PSNR	
	Capacity	***PSNR***	***Capacity***	***PSNR***
Lena	948378	35.22	232365	51.74
Baboon	1013763	34.97	249900	51.36
Pepper	1038439	30.01	237555	51.62
Jet	1038254	30.00	226950	51.91
Airplane	910753	30.74	191549	52.74
Boat	1002498	35.02	244560	51.47
Lake	998313	35.04	244987	51.48
Tiffany	1017169	30.11	228397	51.83
Elaine	1010298	34.96	247009	51.43
Goldhill	994878	35.08	242765	51.52
Cameraman	1018789	30.05	217845	52.16
Carhouse	932328	35.30	233172	51.75
Tank	1047990	30.00	242889	51.49
Truck	980733	35.16	238737	51.60
Couple	985443	35.08	240799	51.53
Zelda	1027092	30.00	230426	51.77
Barbara	979443	35.09	241677	51.54

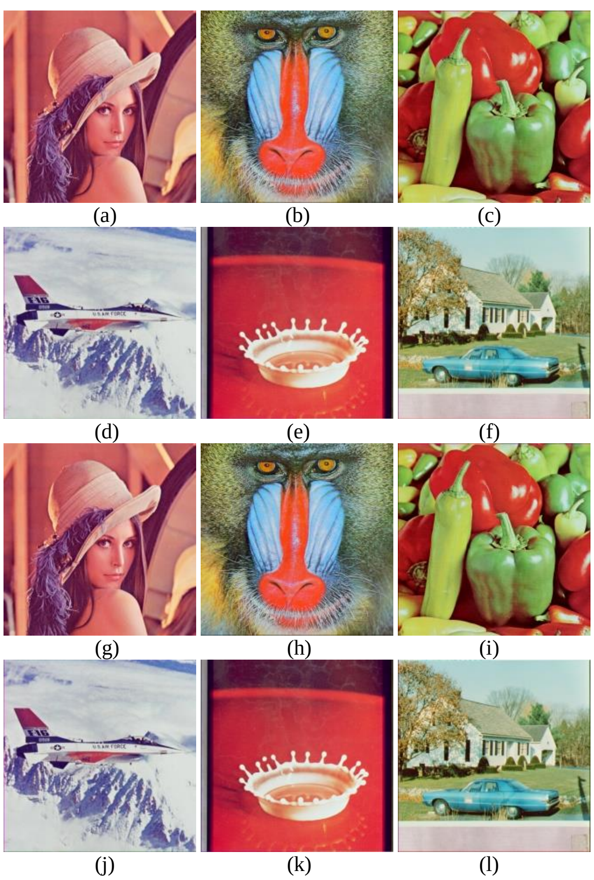

Fig. 5. Color Cover Images: (a) Lena (b) Baboon (c) Peppers (d) Jet (e) Splash (f) Carhouse and (g) – (l) are their Respective Stego Images for Type 18 (k = 4, n = 3).

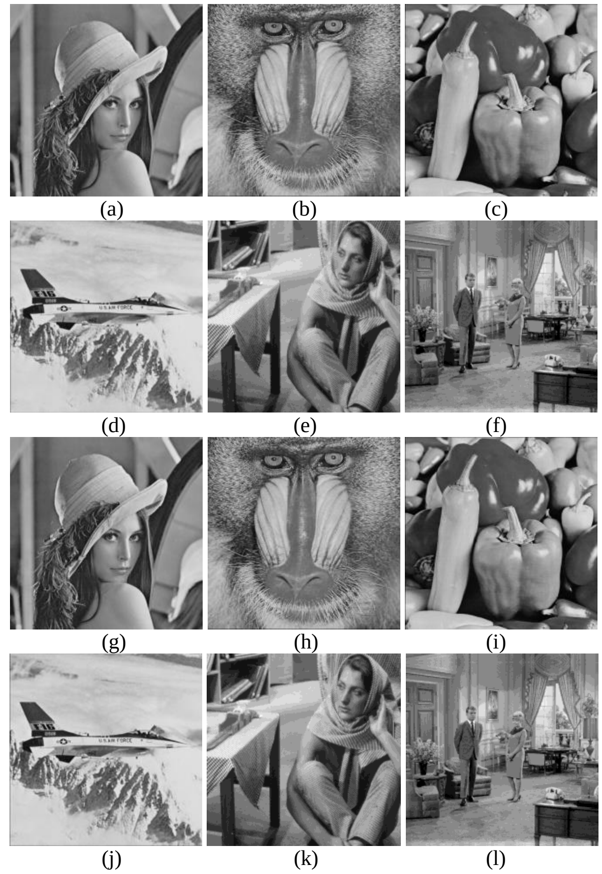

Fig. 6. Gray Cover Images: (a) Lena (b) Baboon (c) Peppers (d) Jet (e) Splash (f) Carhouse and (g) – (l) are their Respective Stego Images for Type 18 (k = 4, n = 3).

V. COMPARATIVE ANALYSIS AND DISCUSSION

To analyse how well the proposed method is working, it is compared to some relevant methods proposed before like Wu and Tsai's method [1], Joo et al.'s method [3], Yang et al.'s method [4], Tseng and Leng's method [5], Mandal and Das's method [7], Prasad and Pal's method [8], Swain's method [9] and Yang and Wang's method [10]. In order to have a comparative analysis of the outcomes of proposed method, Table V and Table VI is constructed to show the comparison between proposed method and other existing methods for color image and gray image respectively. For each existing method, PSNR at the highest capacity is compared with the PSNR of proposed method at the same capacity. From Table V and Table VI, it is evident that proposed method outperformed the existing methods each time. For same capacity, proposed method's PSNR is significantly higher than other methods compared. In case of color image, proposed method's average PSNR is 26.43%, 49.21%, 11.02% and 41.32% higher than that of Mandal and Das's method, Yang and Wang's method, Swain's method and Prasad & Pal's method, respectively. Applying the proposed method on gray images also produces better result than other methods compared. Here also, for same capacity, proposed method's average PSNR is 16.29%, 3.50%, 16.94% and 12.81% higher than the PSNR gained in Wu & Tsai's method, Tseng et al.'s method, Yang et al.'s method and Joo et al.'s methods, respectively.

TABLE. V. COMPARISON BETWEEN PREVIOUS METHODS AND PROPOSED METHOD FOR COLOR IMAGES

Cover Image (512 x 512 x 3)	Mandal and Das's method		Proposed method	Yang and Wang's method		Proposed method	Swain's method		Proposed method	Prasad and Pal's method		Proposed method
	Capacity	***PSNR***	***PSNR***	***Capacity***	***PSNR***	***PSNR***	***Capacity***	***PSNR***	***PSNR***	***Capacity***	***PSNR***	***PSNR***
Lena	1166296	42.26	52.45	196608	41.58	62.14	1341192	46.17	51.89	1976671	31.01	46.34
Baboon	1159328	38.44	52.43	196608	33.29	61.96	1489945	48.49	51.38	2219715	32.29	45.79
Peppers	1167960	42.28	52.42	196608	39.43	62.01	1350251	47.06	51.81	1783210	30.10	46.81
Jet	1165184	42.60	52.51	196608	43.73	62.35	1267690	46.18	52.14	1753707	35.66	46.88
Sailboat	1146224	40.66	52.48	196608	47.41	62.04	1424967	47.29	51.59	2130772	33.11	46.16
Car-House	1162992	41.41	52.49	196608	41.34	62.26	1339985	44.73	51.90	2079088	34.59	46.08
Splash	1173856	42.86	52.52	196608	44.86	62.39	-	-	-	-	-	-

TABLE. VI. COMPARISON BETWEEN PREVIOUS METHODS AND PROPOSED METHOD FOR GRAY IMAGES

Cover Image (512 x 512)	Wu and Tsai's method		Proposed Method	Tseng et al. method		Proposed Method	Yang et al. method		Proposed Method	Joo et al. Method		Proposed Method
	Capacity	***PSNR***	***PSNR***	***Capacity***	***PSNR***	***PSNR***	***Capacity***	***PSNR***	***PSNR***	***Capacity***	***PSNR***	***PSNR***
Lena	407680	41.79	47.51	215740	50.70	52.07	528966	36.75	42.56	407152	43.4	47.52
Baboon	450328	37.90	47.04	241719	48.57	51.50	559222	34.30	42.22	456344	39.2	46.98
Jet	409944	40.97	47.52	204682	50.89	52.37	-	-	-	409768	42.8	47.52
Peppers	405480	41.73	47.50	217290	50.57	52.01	528791	36.83	42.54	406520	42.5	47.49
Elaine	407128	42.1	47.44	-	-	-	-	-	-	407144	43.5	47.44
Tiffany	403764	41.47	47.53	210935	50.86	52.18	528678	36.35	42.49	-	-	-
Boat	418560	39.6	47.29	-	-	-	-	-	-	419920	41.0	47.27
Tank	403990	42.3	47.33	-	-	-	-	-	-	-	-	-
Lake	420912	40.0	47.34	224915	49.86	51.85	535984	36.51	42.41	421296	41.5	47.34
Gold hill	405634	42.20	47.48	-	-	-	529319	37.15	42.51	-	-	-
Zelda	398584	42.66	47.63	-	-	-	526145	37.78	42.60	-	-	-
Barbara	442529	36.24	47.12	-	-	-	548206	34.80	42.33	-	-	-

VI. CONCLUSION

An efficient technique is introduced to hide a significant amount of secret information keeping the distortion unnoticeable. Capacity and PSNR is quite higher than other existing methods discussed. The greatest advantage of our proposed method is, users can easily tailor this method according to their need by taking the desired Type of (k,n). Either to achieve higher capacity or to maintain a higher PSNR, whatever the target may be, just tuning the values of 'k' and 'n' is sufficient. Random embedding order is followed instead of traditional sequential order by hiding secret information into Stable Blocks first than into Unstable Blocks. This step is working as an extra layer of security if any unauthorized attack happens. Since only the sender and recipient know the correct order of extraction, the intruder is supposed to get a meaningless message in that case. Future work may include utilizing the unstable blocks in different way like hiding variable rate secret data instead of fixed 'n' bits secret data.

REFERENCES

[1] D.-C. Wu and W.-H. Tsai, "A steganographic method for images by pixel-value differencing," Pattern Recognition Letters, vol. 24, no. 9-10, pp. 1613–1626, 2003.

[2] C. Wang, N. Wu, C. Tsai and M. Hwang, "A high quality steganographic method with pixel-value differencing and modulus function", Journal of Systems and Software, vol. 81, no. 1, pp. 150-158, 2008.

[3] J. Joo, H. Lee and H. Lee, "Improved Steganographic Method Preserving Pixel-Value Differencing Histogram with Modulus Function", EURASIP Journal on Advances in Signal Processing, vol. 2010, no. 1, 2010.

[4] C. Yang, C. Weng, H. Tso and S. Wang, "A data hiding scheme using the varieties of pixel-value differencing in multimedia images", Journal of Systems and Software, vol. 84, no. 4, pp. 669-678, 2011.

[5] H.-W. Tseng and H.-S. Leng, "A Steganographic Method Based on Pixel-Value Differencing and the Perfect Square Number," Journal of Applied Mathematics, vol. 2013, pp. 1–8, 2013.

[6] W. Zhao, Z. Jie, L. Xin, and W. Qiaoyan, "Data embedding based on pixel value differencing and modulus function using indeterminate equation," The Journal of China Universities of Posts and Telecommunications, vol. 22, no. 1, pp. 95–100, 2015.

[7] J. K. Mandal and D. Das, "Colour Image Steganography based on Pixel Value Differencing in Spatial Domain," IJIST International Journal of Information Sciences and Techniques, vol. 2, no. 4, pp. 83–93, 2012.

[8] S. Prasad and A. Pal, "An RGB colour image steganography scheme using overlapping block-based pixel-value differencing", Royal Society Open Science, vol. 4, no. 4, p. 161066, 2017.G. Swain, "Adaptive pixel value differencing steganography using both vertical and horizontal edges", Multimedia Tools and Applications, vol. 75, no. 21, pp. 13541-13556, 2015.

[9] C.-Y. Yang and W.-F. Wang, "Block-Based Colour Image Steganography Using Smart Pixel-Adjustment," Advances in Intelligent Systems and Computing Genetic and Evolutionary Computing, pp. 145–154, 2015.

[10] C.-K. Chan and L. Cheng, "Hiding data in images by simple LSB substitution," Pattern Recognition, vol. 37, no. 3, pp. 469–474, 2004.

[11] C.-C. Chang and H.-W. Tseng, "A steganographic method for digital images using side match," Pattern Recognition Letters, vol. 25, no. 12, pp. 1431–1437, 2004.

[12] V. Nagaraj, V. Vijayalakshmi, and G. Zayaraz, "Color Image Steganography based on Pixel Value Modification Method Using Modulus Function," IERI Procedia, vol. 4, pp. 17–24, 2013.

[13] M. G. Gouthamanaath and A. Kangaiammal, "Color Image Steganography using Combined Pixel Value Differencing and Pixel Indicator Technique in Spatial Domain," IJCA Proceedings on National Conference on Research Issues in Image Analysis and Mining Intelligence, pp. 20–23, Jun. 2015.

[14] J.-G. Yu, E.-J. Yoon, S.-H. Shin, and K.-Y. Yoo, "A New Image Steganography Based on 2k Correction and Edge-Detection," Fifth International Conference on Information Technology: New Generations (itng 2008), 2008.

[15] T.-S. Chen, C.-C. Chang, and M.-S. Hwang, "A virtual image cryptosystem based upon vector quantization," IEEE Transactions on Image Processing, vol. 7, no. 10, pp. 1485–1488, Oct. 1998.

[16] M. Sabokdast and M. Mohammadi, "A steganographic method for images with modulus function and modified LSB replacement based on PVD," The 5th Conference on Information and Knowledge Technology, 2013.

[17] S. Gupta, A. Goyal, and B. Bhushan, "Information Hiding Using Least Significant Bit Steganography and Cryptography," IJMECS International Journal of Modern Education and Computer Science, vol. 4, no. 6, pp. 27–34, 2012.

[18] T. Denemark and J. Fridrich, "Side-informed steganography with additive distortion," 2015 IEEE International Workshop on Information Forensics and Security (WIFS), 2015.

[19] Chadha A., Satam N., Sood R., and Bade D., "An Efficient Method for Image and Audio Steganography using Least Significant Bit Substitution," International Journal of Computer Applications, vol. 77, no. 13, pp. 37-45, 2013.

[20] M. Hussain and M. Hussain, "A Survey of Image Steganography Techniques," International Journal of Advanced Science and Technology, vol. Vol. 54, pp. 113–124, May 2013.