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An Image Steganography Method Resistive to fall off Boundary Value Problem with Five Pixel Pair Differencing

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Abstract

Although secret information can be securely hidden in the cover image using PVD approach, it suffers from fall off boundary problem especially when the pixel values are close to the boundaries. In the PVD approach, the pixel values of two pixels in a pair are so adjusted that the difference between these two pixel values represents the hidden information. But in this process, sometimes the pixel values exceed the boundaries and the cover image becomes unsuitable for hiding secret information. The proposed method is robust against the fall off boundary problem. Cover image is partitioned in the blocks of 2×3 pixels forming five pairs in each block. Difference value is calculated for each pair. If the difference value of at least one pair is greater than 127, the block is marked as edged block otherwise it is marked as smooth block. Fall off boundary problem is severe for edged blocks. Hence LSB substitution method is used for hiding secret data in the edged block and PVD approach is used for hiding secret data in smooth block. A separate selection process is used for selecting edged blocks for hiding secret data since hiding data using LSB substitution method can convert it into smooth block. This conversion of edged block into smooth block during embedding process results in the unsuccessful extraction of original secret data during extraction. The proposed method provides improved hiding capacity and PSNR values in comparison with existing image steganography methods based on PVD approach.

Keywords: PVD Steganography, LSB Substitution, Fall off boundary value problem, Information hiding, PSNR

1. Introduction

Wu et al. [1] has proposed a steganography method based on pixel value differencing approach. The method uses gray scale images as cover images. The cover image is read as a two dimensional array and partitioned into non overlapping blocks of two consecutive pixels. Assuming P_i and P_{i+1} be the two pixels in the block, the difference value d_i is calculated for each block by subtracting P_i from P_{i+1}. Since the gray scale cover images are used for embedding secret information, a range table R, with table range from 0 to 255, is designed with *n* sub ranges R_k where k = 1,2,3,…..,n. A suitable sub range from the range table is located using the difference value $|d_i|$. The width of the sub range, w_k ($w_k = u_k - l_k + 1$), is used to estimate the number of bits t_i ($t_i = \log_2 w_k$) of secret information to be hidden in the block. The values of P_i and P_{i+1} are adjusted in such a way that the difference stands for the hidden secret information. During extraction, the difference value d'_i for each block of two consecutive pixels P_i and P_{i+1} in the stego-image is calculated. $|d'_I|$ is used to locate the suitable sub range R_k from the range table R. The decimal equivalent of the secret information hidden in the block is given by $|d'_i|-l_k$ which is then transformed into a binary sequence with t_i bits[1].

In the PVD method, the cover image is partitioned in the non overlapping blocks of two consecutive pixels in either horizontal or vertical direction. Thus the two consecutive pixels represent a vertical/ horizontal edge, but the edge can have different directions. Chang et al. [2][3] has proposed a steganography method. The method hides secret information in a block of four pixels with a vertical, a diagonal and a horizontal edge. The method partitions the cover image into non overlapping blocks of 2 × 2 pixels. The pixels $P_{(x,y)}$, $P_{(x+1,y)}$, $P_{(x,y+1)}$ and $P_{(x+1,y+1)}$ forms the block where x and y represents the pixel locations. Pixel $P_{(x,y)}$ is used as common pixel to form three pixel pairs with the other three pixels in the block. These three pairs are PP_0, PP_1 and PP_2 where $PP_0 = (P_{(x,y)},P_{(x+1,y)})$, $PP_1 = (P_{(x,y)}, P_{(x,y+1)})$ and $PP_2 = (P_{(x,y)}, P_{(x+1,y+1)})$, respectively. The difference value d_i is calculated by subtracting the common pixel from the other pixel in the pair. The PVD approach [1] is used to hide secret information in each pair of the block. The secret information is embedded in the pair by adjusting the two pixel values of the pair. The new pixel values in each pair are different from their original values. Thus the common pixel $P_{(x,y)}$ may have three different values in three pair. Proper value is assigned to the common pixel $P_{(x,y)}$ by selecting one pair as the reference pair. Values for other pixels are calculated using the pixel values of reference pair and a new block of 2 × 2 pixels is reconstructed with new pixel values [2][3].

Xin Liao et al [4], M.B. Ould MEDENI [5] and M. Khodaei et al [6] has combined pixel value differencing approach with 3 bit LSB substitution method to hide secret information in the gray scale cover image.

Mandal et al. [7] has proposed an adaptive steganography method resistive to fall off boundary value problem using a modified pixel-value differencing approach through management of pixel values within the range of gray scale. Position where the pixels exceeds boundary has been marked and a delicate handle is used to keep the value within the range. The secret information is hidden in the pair using PVD approach. If the new pixel values exceed the boundaries, a modified PVD approach is used to calculate new pixel values.

$(p'_i, p'_{i+1}) = (p_i-m, p_{i+1})$ if $p_{i+1} \geq p_i$ and p_{i+1} crossing the upper range [i.e. 255]

$(p'_i, p'_{i+1}) = (p_i, p_{i+1}-m)$ if $p_{i+1} < p_i$ and p_i crossing the upper range [i.e. 255]

$(p'_i, p'_{i+1}) = (p_i, p_{i+1}+m)$ if $p_{i+1} \geq p_i$ and p_i crossing the lower range [i.e. 0]

$(p'_i, p'_{i+1}) = (p_i+m, p_{i+1})$ if $p_{i+1} < p_i$ and p_{i+1} crossing the lower range [i.e. 0]

Chung Ming Wang et al. [8] has proposed a high quality steganography method resistive to fall off boundary problem with pixel-value differencing and modulus function. The method uses a PVD approach to calculate the difference between two consecutive pixels and the modulus operation to calculate the remainder of two consecutive pixels. The secret information is hidden in the pair by modifying the remainder. For the sub block F_i with pixels $P_{(i,x)}$ and $P_{(i,y)}$, the difference value d_i is obtained as the difference between the pixels $P_{(i,x)}$ and $P_{(i,y)}$. This difference value d_i is used to determine number of bits of secret message t_i and decimal value t'_i of t_i. Then the remainder values are computed as given below

$P_{rem(i,x)} = P_{(i,x)} \bmod t'_i$

$P_{rem(i,y)} = P_{(i,y)} \bmod t'_i$

$F_{rem(i)} = (P_{(i,x)} + P_{(i,y)}) \bmod t'_i$

Secret data of t_i bits is embedded into F_i by altering $P_{(i,x)}$ and $P_{(i,y)}$ such that $F_{rem(i)} = t'_i$ to obtain $P'_{(i,x)B}$ and $P'_{(i,y)}$. When the stego pixel values $P'_{(i,x)B}$ and $P'_{(i,y)}$ do not overflow the boundary of the grayscale pixel value ([0 255]), the embedding process is completed following the replacement of ($P_{(i,x)}$ and $P_{(i,y)}$) by ($P'_{(i,x)B}$ and $P'_{(i,y)}$). In case $P'_{(i,x)}$ or $P'_{(i,y)}$ overflows $P'_{(i,x)}$ and $P'_{(i,y)B}$ are readjusted.

Gulve et al. [9-10] has proposed a steganography method based on PVD approach providing a partial solution for fall off boundary value problem. The cover image is partitioned into blocks of 2 × 3 pixels forming five pixel pairs. The difference between two pixels of a pair is calculated and used to estimate t_i. Then the average of number of bits to be hidden in the five pairs of the block is calculated. The original difference is revised to $d1_i$ as d_i mod $2^{average}$. The revised difference $d1_i$ is used to hide secret information in each pair. The method provides a partial solution to the fall off boundary value problem. If one or more pixel values falls below the lower boundary (i.e. 0), the smallest pixel value is searched and absolute value of the pixel with smallest value is added in all the pixels. If one or more pixel value exceed the upper boundary (i.e. 255), the largest pixel value is searched. The difference between largest value and 255 is subtracted from all the pixels. The proposed method not only provides a partial solution for fall off boundary value problem but also improves the hiding capacity of the cover image and security of the secret information hidden in the cover image.

2. Proposed Method

In the gray scale images, pixel values ranges from 0 to 255. The pixel value differencing approach uses the difference between two pixels in the pair to embed the secret information. After embedding the secret information, the values of two pixels are so adjusted that the difference stands for the embedded secret information. In this process it is possible that the pixel values exceeds the range i.e. pixel value can fall below 0 or exceed 255. Since the pixel values ranges from 0 to 255, the pixel values falling below 0 are rounded to 0 and pixel values exceeding 255 are rounded to 255 while constructing the stego image. If the pixel in the pair exceeds the boundaries during embedding process, the cover image becomes unsuitable for data hiding. Such pairs from the stego image do not reveal accurate secret data embedded in them. Mandal et al. has shown that the pixels may take values from -64 to 319 after embedding secret information.

Gulve et al. [9-10] has used a block of 2 × 3 pixels to embed the secret information. In a block of 2 × 3 pixels, five pixel pairs are formed and then PVD approach is used to embed secret information. The pixel adjustment process used in the embedding algorithm provides a solution to fall off boundary value problem. Since the fall off boundary value problem occurs rarely in the image, the pixel adjustment process does not affect the overall quality of the stego image. Still the pixel adjustment process does not provide a guaranteed solution to fall off boundary value problem. The example given below demonstrates the fall off boundary value problem occurred when the method suggested by Gulve is used to embed secret information in a block of pixels.

P_1 0	P_2 1	P_3 0
P_4 255	P_5 1	P_6 0

Figure 1 Pixel block

Consider a block of 2 × 3 pixels as shown in Figure 1. Pixel P_2 is used as common pixel and five pairs are formed as [0, 1], [0, 1], [255, 1], [1, 1], [0, 1]. A range table with sub ranges [0-7], [8-15], [16-31], [32-63], [64-127], [128-255] and width w_i ={ 8, 8, 16, 32, 64, 128 } is used. The difference d_i is calculated by subtracting common pixel from the other pixel in the pair. The difference values are d_i={-1,-1,254,0,-1}. The absolute value of difference, $|d_i|$, is used to locate suitable range in the range table.

The range width is used to decide the number of secret message bits (b) to be hidden in each pair. The number of to be embedded secret message bits in five pairs of the block are [3, 3, 7, 3, 3]. The average of secret message bits to be hidden in each pair of the block is 3. The new difference $|d1_i|$ is calculated as $|d1_i|$= remainder ($|d_i|/2^{avg}$). The difference $|d_i|$ is modified to new difference $|d1_i|$ as [1,1,6,0,1] with offset difference, OD_i, as [0,0,248,0,0]. The offset difference for each pair is calculated as $|d_i| - |d1_i|$. The new difference $|d1_i|$ is used to estimate number of secret message bits to be hidden in each pair of the block. Hence actual number of secret message bits to be embedded in the five pairs of the block is [3, 3, 3, 3, 3]. The new difference value d'_I is calculated as OD_i+l_i+b where l_i is the lower boundary of the range and *b* is decimal equivalent of b secret message bits. The m values are calculated as $d'_I - d_i$. Assuming the m values to be -2, -2, -3, 6, -5, the new pixel values are calculated for each pair. The pairs with new pixel values are [-1, 2], [-1, 2], [253, 2], [4,-2], [-2, 4]. Pixel P_2 has different values in each pair. But it can have only one value. Hence pair with minimum |m| is used as reference pair and it is used to calculate values of other pixels in remaining four pairs. For the pair with minimum |m|, the new pixel values of the pixels are close to their original values. The pair [P_1, P_2] is used as reference pair and used to calculate values of four pixels P_3, P_4, P_5, P_6. The pairs with new pixel values are [-1, 2], [-1, 2], [253, 2], [8, 2], [-4, 2]. The new block constructed is shown in Figure 2.

P_1 -1	P_2 2	P_3 -1
P_4 253	P_5 8	P_6 -4

Figure 2 New pixel block

In Figure 2, pixels P_1, P_3 and P_6 are exceeding the boundaries. Hence the pixel adjustment process suggested by Gulve [9-10] is used to adjust them. The new block obtained after pixel adjustment process is shown in Figure 3.

P_1 3	P_2 6	P_3 3
P_4 257	P_5 12	P_6 0

Figure 3 Pixel block obtained after pixel adjustment

Still the pixel P_4 in the block shown in Figure 3 is exceeding the upper boundary. Hence the block is not useful for embedding secret data.

If the difference value is less than 128, the pixel adjustment process suggested by Gulve [9-10] provide the solution for fall off boundary value problem but the possibility of occurrence of fall off boundary value problem increases if the difference value of at least one pair exceeds 127.

The proposed method combines the PVD approach and LSB substitution method to avoid the fall off boundary value problem. The method categories each block as smooth block or edged block. Block with difference value of at least one pair ≥ 128 is called as edged block and the block with difference value for all the pairs ≤ 127 is called as smooth block. A PVD approach is used to embed secret information in the smooth block and 3 bit LSB substitution method is used to embed secret information in the edged block. But using 3 bit LSB substitution method to embed secret information in the edged block may convert it into smooth block. The conversion of edged block into smooth block may result into use of PVD approach to extract secret information instead of 3 bit LSB substitution method where secret information is originally embedded using 3 bit LSB substitution method. Hence there is a need to carefully select an edged block to embed secret information. The embedding of 3 bit secret message in the pixel may change its value by ±7. Since there are two pixels in a pair, four possibilities exist. Assume P1=8 and P2=136.

Possibility 1: Original pair [8,136] changed to [15, 129] after adding 7 into P1 and subtracting 7 from P2. The new difference value is 114.

Possibility 2: Original pair [8,136] changed to [15, 143] after adding 7 into P1 and adding 7 into P2. The new difference value is 128.

Possibility 3: Original pair [8,136] changed to [1, 129] after subtracting 7 from P1 and subtracting 7 from P2. The new difference value is 128.

Possibility 4: Original pair [8,136] changed to [1, 143] after subtracting 7 from P1 and adding 7 into P2. The new difference value is 135.

From above four possibilities, it is obvious that every edged block cannot be used for hiding secret information using 3 bit LSB substitution method since the difference value may fall below 128. For the edged block, if the difference value falls below 128 during embedding process, it is considered as smooth block in the extraction process. Considering the above four possibilities, the edged block can be safely used for embedding secret information using 3 bit LSB substitution method if the difference value of at least one pair is ≥ 142. Thus even for possibility 1, the new difference will always be ≥ 128 and the edged block will be identified properly during extraction process. Hence the edged blocks having difference value of at least one pair ≥ 142 can only be used for embedding secret information and the edged block not satisfying this condition remains unutilized.

From the above discussion, it is clear that all the edged blocks cannot be used for embedding secret information using 3 bit LSB substitution method. Hence it is necessary to mark edged blocks as used or unused in the embedding process only. This is done by setting the LSB of pixel $P_{(x,y)}$ to 0 for unused edged block and 1 for used edged block. For the used edged block, the secret data is embedded in the remaining five pixels using 3 bit LSB substitution method.

Marking of the edged block as unused block should be done carefully, especially when $P_{(x,y)} > P_{(x,y+1)}$ and the absolute difference between $P_{(x,y)}$ and $P_{(x,y+1)}$ is exactly 128. Consider the pair ($P_{(x,y)}$, $P_{(x,y+1)}$) with pixel values $P_{(x,y)} = 129$ and $P_{(x,y+1)} = 1$ and this is the only pair in the block having difference ≥ 128. Setting the LSB of $P_{(x,y)}$ to 0 will modify its value to 128 and the difference will be 127. Thus the edged block will be interpreted as smooth block in the extraction process and incorrect data will be retrieved from it.

The algorithm of Gulve [9-10] is modified to make it resistive to fall off boundary value problem. The algorithm for embedding the secret information in the cover image is given below.

1. Read the cover image in 2- dimensional decimal array.
2. Partition the array into non-overlapping blocks of 2 × 3 pixels
3. Form five pixel pairs and calculate the difference values d_i for the each pixel pair in the block using eq. (1)

$$\left.\begin{aligned} d_0 &= P_{(x,y)} - P_{(x,y+1)} \\ d_1 &= P_{(x,y+2)} - P_{(x,y+1)} \\ d_2 &= P_{(x+1,y)} - P_{(x,y+1)} \\ d_3 &= P_{(x+1,y+1)} - P_{(x,y+1)} \\ d_4 &= P_{(x+1,y+2)} - P_{(x,y+1)} \end{aligned}\right\} \tag{1}$$

4. Find maximum difference using eq. (2)

$$\text{maxdiff} = \text{maximum}[d_0, d_1, d_2, d_3, d_4] \tag{2}$$

5. Mark the block as either edged block or smooth block by setting blockuseflag to either 1 or 0 using eq. (3)

$$\left.\begin{aligned} \text{blockuseflag} &= 1 \quad \text{if maxdiff} > 127 \\ \text{blockuseflag} &= 0 \quad \text{if maxdiff} \leq 127 \end{aligned}\right\} \tag{3}$$

6. If blockuseflag = 1 and maxdiff > 141, mark the edged block as used block by setting LSB of the pixel $P_{(x,y)}$ to 1. Hide 3 secret message bits in each of the remaining five pixels in the block and go to step 19.
7. If blockuseflag = 1 and 128 ≤ maxdiff ≤ 141 then mark the edged block as unused block by setting the LSB of pixel $P_{(x,y)}$ to 0 using the following conditions and go to step 19.
   a. If $|P_{(x,y)}-P_{(x,y+1)}| = 128$ and $P_{(x,y)} = 255$ then subtract 1 from $P_{(x,y)}$ and $P_{(x,y+1)}$ maintaining the difference between $P_{(x,y)}$ and $P_{(x,y+1)}$ to 128.
   b. If $|P_{(x,y)}-P_{(x,y+1)}| = 128$ and $P_{(x,y)} > P_{(x,y+1)}$ and $P_{(x,y)} < 255$ then add 1 to $P_{(x,y)}$ if $P_{(x,y)}$ is a odd value else do not change its value.
   c. If $|P_{(x,y)}-P_{(x,y+1)}| > 128$, set the LSB of pixel P(x,y) to 0.
8. If blockuseflag = 0, perform the following steps to embed the secret information in the five pixel pairs of the block using PVD approach.
9. Use $|d_i|$ where i = 0,1,2,3,4 to locate suitable range $R_{i,k}$ in the designed range table. Use this range to calculate number of bits t_i to be embedded in each pair P_i. Then calculate the average of the bits using eq. (4)

$$Avg = \frac{\sum_{i=0}^{4} t_i}{5} \tag{4}$$

10. Calculate the revised difference $|d1_i|$ where i = 0,1,2,3,4 as $|d1_i|$ = remainder($|d_i|/2^{avg}$) so that $d1_i \leq 2^{avg}$
11. Calculate the offset difference OD_i as $OD_i = |d_i| - |d1_i|$ for each pixel pair.
12. Use $|d1_i|$ where i = 0,1,2,3,4 to locate suitable range $R_{i,k}$ in the designed range table.
13. Compute the number of bits t_i that can be embedded in each pair using the corresponding range given by $R_{i,k}$. The value t_i can be estimated from the width w_k of $R_{i,k}$, which is given by $t_i = \log_2 w_{i,k}$ where width $w_{i,k} = u_{i,k} - l_{i,k} + 1$ and $u_{i,k}$ and $l_{i,k}$ are upper and lower boundaries of the range $R_{i,k}$.
14. Read t_i bits from the binary secret data and transform the bit sequence into a decimal value b.
15. Calculate the new difference value d'_i using eq. (5)

$$\left.\begin{array}{ll} d'_i = OD_i + l_{i,k} + b_i & \text{if } d_i \geq 0 \\ d'_i = -(OD_i + l_{i,k} + b_i) & \text{if } d_i < 0 \end{array}\right\} \tag{5}$$

16. Modify the values of pixels in pixel pair P_i by using eq. (6)

$$(P'_n, P'_{n+1}) = \left(P_n - \left\lceil \frac{m}{2} \right\rceil, P_{n+1} + \left\lfloor \frac{m}{2} \right\rfloor \right) \tag{6}$$

where P_n and P_{n+1} represents two pixels in the pair P_i and m is the difference between d_i and d'_i.

17. Select the pair with minimum $|m|$ as the reference pair and use this pair to adjust the values of pixels of the other four pairs. The value of the common pixel is given by P'_n of the reference pair. Modify value of other pixels P'_{n+1} of each pair such that the new difference d'_i for each pair will remain unchanged. Thus new values are assigned to remaining four pixels in the block.
18. Check the new pixel values for fall off boundaries i.e. check whether all the pixel values are within the range 0 to 255. If not, modify the pixel values of each pair preserving the difference value.
   a. Find out smallest of all the pixel values. If smallest value is less than 0, add |smallest| in all the pixel values in that block.
   b. Find out largest of all the pixel values. If largest value is greater than 255, subtract (largest – 255) from all the pixel values in that block.
   c. If fall of boundary problem still persists, then the cover image is not suitable for hiding secret data.

19. Now, reconstruct the block with modified pixel values.
20. Repeat the embedding process from step 3 to 19 till the message gets embedded in the cover image.

To extract the secret information hidden in the stego image, the image is read as 2D array and partitioned in the blocks of 2 × 3 pixels. The maximum difference is calculated from the difference values of five pairs in the block. For the smooth blocks, PVD approach is used to extract secret information embedded in the pairs. For the edged blocks, LSB of pixel $P_{(x,y)}$ is extracted. If the decimal equivalent of LSB is 1, 3 LSB's of each of the remaining five pixels in the block are extracted otherwise the block is skipped.

The algorithm for extraction of the secret information from the stego-image is given below.

1. Read the cover image in 2- dimensional decimal array.
2. Partition the array into non-overlapping blocks of 2 × 3 pixels. Keep the partition order same as data embedding.
3. Calculate the difference values separately for each block in the stego-image using eq. (7)

$$\left.\begin{aligned} d_0 &= P_{(x,y)} - P_{(x,y+1)} \\ d_1 &= P_{(x,y+2)} - P_{(x,y+1)} \\ d_2 &= P_{(x+1,y)} - P_{(x,y+1)} \\ d_3 &= P_{(x+1,y+1)} - P_{(x,y+1)} \\ d_4 &= P_{(x+1,y+2)} - P_{(x,y+1)} \end{aligned}\right\} \quad (7)$$

4. Find maximum difference using eq. (8)

$$\text{maxdiff} = \text{maximum}[d_0, d_1, d_2, d_3, d_4] \quad (8)$$

5. Mark the block as either edged block or smooth block by setting blockuseflag to either 1 or 0 using eq. (9)

$$\left.\begin{aligned} \text{blockuseflag} &= 1 \quad \text{if maxdiff} > 127 \\ \text{blockuseflag} &= 0 \quad \text{if maxdiff} \leq 127 \end{aligned}\right\} \quad (9)$$

6. If blockuseflag =1 and LSB of pixel $P_{(x,y)}$ =1, extract 3 LSB's of each of the remaining five pixels in the block and then go to step 13.
7. If blockuseflag =1 and $P_{(x,y)}$ = 0, skip the block and go to step 13
8. If blockuseflag = 0, perform the following steps
9. Use $|d_i|$ where i = 0,1,2,3,4 to locate suitable range $R_{i,k}$ in the designed range table. Use this range to calculate number of bits t_i that is hidden in each pair P_i. Then calculate the average of the bits using eq. (1)
10. Calculate the revised difference $|d1'_i|$ where i = 0,1,2,3,4 as $d1'_i$ = remainder(d_i/ 2^{avg})
11. Use $|d1'_i|$ where i = 0,1,2,3,4 to locate suitable $R_{i,k}$ in the designed range table
12. After $R_{i,k}$ is located, $l_{i,k}$ is subtracted from $|d1'_i|$ and b'_i is obtained in decimal form. b'_i represents the secret information hidden in that pair in decimal form. A binary sequence is generated from b'_i with t_i bits where $t_i = \log_2 w_{i,k}$.
13. Repeat steps from 2 to 12 till embedded information gets extracted.

3. Results

For experimentation, a set of 325 grey scale images in tiff format is used. The set has images from the "The USC-SIPI Image Database (http://sipi.usc.edu/database/)", the BOSS rank database and images taken by Canon A45 camera. The images taken from the camera are resized and converted into tiff format. The images from BOSS rank database are converted into tiff format and images having minimum and maximum pixel values close to boundary values are selected from BOSS rank data base. The text files covering the full hiding capacity of cover image are generated randomly and used as secret information.

The statistics showing the number of edged blocks, used edged blocks and unused edged blocks is shown in Table 1. For the BOSS rank image set with 1000 images, the average used blocks are 150 and average unused blocks are 124.

Table 1 Statistics of used and unused blocks for standard images

Cover Image	Total edged blocks	Used Edged blocks	Unused Edged blocks
Elaine	0	0	0
Couple	26	6	20
Sailboat	68	41	27
Baboon	217	107	110
Lena	23	8	15
Tank	0	0	0
Peppers	114	79	35
Barbara	121	36	85
Boat	136	87	49

The hiding capacity of the cover image and PSNR value obtained after embedding secret data in the cover image are compared with Mandal' method [7] , Wang's method [8] and Gulve's method [10] method. The comparison is shown in table 2.

Table 2. Comparison of hiding capacity (in bytes)

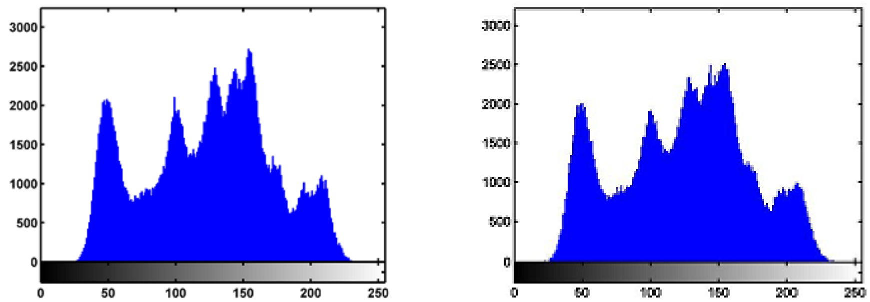
Cover image	Mandal's PVD Method [7]		C M Wang's Method [8]		Gulve's Method[10]		Proposed method	
	Capacity	PSNR	Capacity	PSNR	Capacity	PSNR	Capacity	PSNR
Lena	51370	40.61	51219	44.1	81631	42.86	81598	42.26
Baboon	57583	36.67	57246	40.3	82116	41.99	81864	39.70
Peppers	51107	40.61	50907	43.3	81650	42.80	81577	42.19
Elaine	51070	41.47	51074	44.8	81603	42.42	81603	42.13
Boat	52631	39.04	52635	42.1	81699	42.31	81581	41.63

Figure 4 shows the cover images and the corresponding stego images obtained using the proposed method. The cover and the stego images are indistinguishable by human visual system.

Cover image Stego image

Figure 4 Cover and stgeo images

Figure 5 shows the histogram of the cover and stego images obtained using the proposed method. It can be observed that the shape of the histogram is preserved after embedding the secret data.



Cover image Stego image

Figure 5 Histogram of cover and stego image

The pixel values of cover image are subtracted from stego image and histogram is plotted for the difference values. This histogram is shown in Figure 6. It can be observed that most of the difference value lies between 15 and -15. This proves that the deviation in the pixel values of cover image is very small even after hiding the secret information utilizing the full hiding capacity. Hence the proposed method is robust against histogram analysis attack.

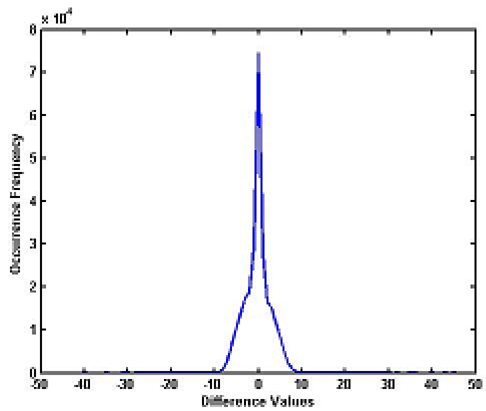


Figure 6 Difference histogram

Text files, having size in multiple of 10 Kb are embedded in lena.tiff. The stego images so obtained are tested under the RS steganalysis [11]. It is observed from Figure 7 that the difference between R_M and R_{-M}, S_M and S_{-M} is very small. The rule $R_M \cong R_{-M}$ and $S_M \cong S_{-M}$ is satisfied for the output images. So the proposed method is secure against RS attack.

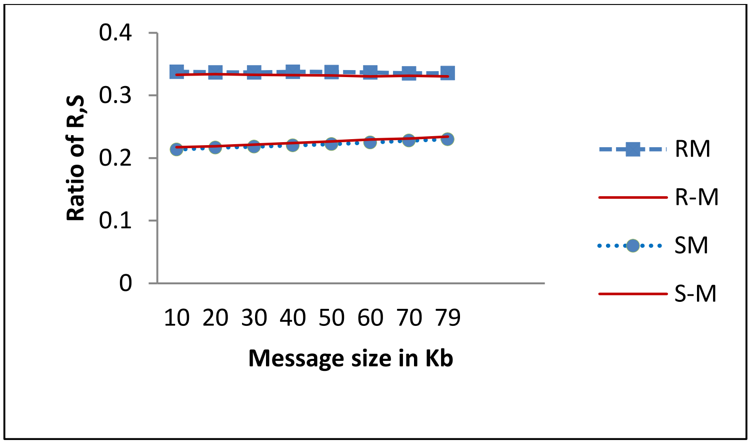


Figure 7 RS Diagram

PSNR, MSE and Universal Quality Index (Q) [12] are the most common metrics used for evaluating quality of the stego image. PSNR measures the distortion caused by data hiding in the original cover image. Higher PSNR values are the indication of good quality of the stego image. PSNR is given by (10)

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

Mean square error (MSE) is given by (11)

$$MSE = \frac{\sum_{M,N}[I_1(m,n) - I_2(m,n)]^2}{M*N} \quad (11)$$

where I_1 and I_2 represents cover image and stego image respectively.

The embedding rate is calculated for each cover image in terms of bpp. The proposed method has the average embedding rate of ~2.48 bpp. The quality of the stego image is analyzed using PSNR, MSE and universal image quality index [12]. The universal image quality index measures the structural distortion occurred during the image degradation process. Table 3 shows the PSNR values, MSE and universal quality index [12] for different images obtained using proposed method. The PSNR values are above the threshold of 36 dB and Universal Quality Index (Q) values are close to 1, which proves that the stego images are visually indistinguishable from original cover images.

The detection rate of the proposed method is calculated using Ensemble Classifiers [13]. Experiments are carried out with the BOSS image data set with 1000 images. 686 SPAM features [14] are extracted from each image. The proposed method has the detection rate of 0.04 for 0.2 bpp and 0.003 for 0.5 bpp. The detection rate for the proposed method is high as compared to HUGO. But this is obvious because HUGO [15] uses the detectability map to minimize the embedding impact. Also HUGO uses 1 bit LSB technique for embedding. The proposed method uses PVD approach for embedding which embeds at least 3 bits in a pair. So for 0.2 bpp embedding rate with cover image resolution 512 x 512, HUGO uses ~ 52428 pixels where as the proposed approach uses at the most 3496 blocks (~ 20976 pixels). Considering this fact, the high detection rate is justified. It is possible to increase the undetectability by narrowing the width of sub ranges in the range table. But PVD methods are designed to provide high payloads (embedding capacity of cover image) and narrowing the width of sub ranges will violet this motivation of PVD approach.

Table 3 Results

Cover Image	Hiding Capacity (Bytes)	PSNR	MSE	Q
Elaine	81603	42.13	3.98	0.92
Couple	81620	41.72	4.38	0.93
Sailboat	81696	41.32	4.80	0.91
Baboon	81864	39.70	6.98	0.97
Lena	81598	42.26	3.87	0.85
Tank	81595	42.43	3.71	0.93
Peppers	81577	42.19	3.92	0.87
Barbara	81827	40.50	5.80	0.89
Boat	81581	41.63	4.47	0.92

4. Conclusion

The image steganography methods that use LSB method to hide secret information are not prone to fall of boundary problem. But fall of boundary problem is common for the steganography method that uses pixel value differencing approach to hide secret information. The problem becomes severe for the images when the pixel values in the block are close to boundaries making the image unsuitable for hiding the secret information. Hence there is need of careful selection of cover images when PVD steganography is used. The proposed method provides a solution for the fall off boundary value problem.

Data hiding capacity, quality of stego image and security are the important factors of the steganography system. The proposed method not only provides a solution for fall off boundary problem but also provides improvement in the data hiding capacity and security of secret data. The improvement in the data hiding capacity is made possible by taking a larger block size of 2 × 3 pixels. The block of 2 × 3 pixels helps in increasing the number of pairs which in turn provides increased data hiding capacity. Experimentally it is verified that 2 × 3 is the optimum block size and if the block size is further increased, it affects the performance of the steganography system.

The proposed method modifies the difference value before using it for hiding secret information. This modified difference value is used to hide secret information. Thus during extraction, the actual difference value do not stand for the secret information and it is not possible to extract correct secret information hidden in the pair unless the difference value if modified again. The security is further improved by combining PVD and LSB steganography methods. All the edged blocks are not used for hiding secret information. Instead, on the basis of difference, the edged blocks are selected for hiding secret information using LSB substitution method. Identification of edged block used for hiding secret information will be a challenging task. Thus, even in case of detection of steganography, extraction of secret information from the stego image will be a difficult task.

The proposed method also improves the PSNR values. Experimental results prove that the proposed method passes the visual attack, Histogram Analysis attack and RS steganalysis. The improvement in PSNR values is due to two reasons- the number of bits embedded in each pair is limited to the average value of number of bits to be embedded in each pair of that block and the selection of reference pair with minimum |m| which results in at least two pixel values to be very close to their original values after embedding secret data. The good PSNR values are the indication of good quality of stego images.

Considering the fact that no steganography system is secure against all kinds of steganalysis attacks, the sender should avoid using standard images available on the internet as cover images. For safe transmission of secret information, the cover images should be freshly created and should be immediately destroyed after creating the stego images.

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