ITC 4/47

Journal of Information Technology and Control
Vol. 47 / No. 4 / 2018
pp.714-727
DOI 10.5755/j01.itc.47.4.19593

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Received 2017/12/03 | Accepted after revision 2018/10/18

http://dx.doi.org/10.5755/j01.itc.47.4.19593

A Data Hiding Technique by Mixing MFPVD and LSB Substitution in a Pixel

Gandharba Swain

Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India-522502, gswain1234@gmail.com

Corresponding author: gswain1234@gmail.com

Pixel difference range mismatch at sender and receiver is a major problem with pixel value differencing (PVD) steganography techniques. This paper proposes a new steganography technique combining modulus function PVD (MFPVD) and least significant bit (LSB) substitution to address the range mismatch problem. It uses 2×3 size pixel blocks to utilize the edges in five directions. The two LSBs of all the pixels of the block form the lower bit plane block. It is also known as remainder block. Similarly, the six most significant bits (MSBs) of all the pixels of the block form the higher bit plane block. It is also known as quotient block. The quotient block is formed by applying quotient division on all the pixels of the pixel block. Similarly, the remainder block is formed by applying remainder division on all the pixels of the pixel block. MFPVD is applied on the quotient block. The central quotient in the quotient block is considered as reference value and five difference values with five neighboring quotients are calculated. Based on the average of these five difference values, the hiding capacity in all the five directions is decided. The central remainder value in the remainder block acts as an indicator to represent the number of bits hidden in each of these five quotients, so that data extraction can be done successfully. In remaining five remainders LSB substitution is applied. The experimental results prove that there are no step effects in pixel difference histograms of stego-images. It means that the pixel difference histogram (PDH) analysis cannot detect this proposed technique. Further, it is also justified that the proposed technique achieves higher hiding capacity as compared to the existing techniques without compromising the peak signal-to-noise ratio (PSNR).

KEYWORDS: Steganography, PVD, MF PVD, PDH analysis, RS analysis, data hiding.

1. Introduction

Pixel value differencing (PVD) steganography is one of the popular data hiding techniques in spatial domain. The primary goal of this technique is to hide more number of bits in edge regions as compared to the smooth regions. The first PVD steganography technique used pixel value differencing in 1×2 pixel blocks [27]. In this technique the hiding capacity is much lesser. The hiding capacity has been improved by using 2×2 pixel blocks in [3, 10]. The hiding capacity and security is further improved by utilizing multidirectional edges in 3×3 pixel blocks [5]. It has been found that the pixel difference histogram (PDH) analysis can detect the

PVD steganography [14]. PDH is a curve with pixel difference on X-axis and frequency on Y-axis. For an original image it is a smooth curve, without any zig-zag appearance. This zig-zag appearance is known as step effect. In PDHs of stego-images of PVD technique step effect is identified. Wang et al. proposed a PVD steganography using modulus function (MF) [26]. Instead of the pixel value difference, the remainder of pixel value division is utilized to hide the secret bits. This technique gives higher hiding capacity and lower distortion. Zhao et al. advanced this PVD technique by using indeterminate equation and achieved higher peak signal-to-noise ratio (PSNR) [29].

In PVD steganography, if the quantization range is different for different blocks, then it is known as adaptive PVD. An adaptive PVD using 1×3 pixel blocks is proposed in [12]. Subsequently to improve upon the hiding capacity and PSNR, 2×2 pixel block adaptive PVD and 2×3 pixel block adaptive PVD have been proposed in [19] and [15], respectively. A mixture of least significant bit (LSB) substitution and non-adaptive PVD is proposed using 1×3 pixel blocks by Khodaei and Faez [8]. In this technique, data hiding is performed using LSB substitution in middle pixel and PVD in its neighboring pixels. This technique suffers with fall off boundary problem (FOBP) and detected by PDH analysis. These two drawbacks are addressed in [22] using modified LSB substitution and PVD in 2×3 and 3×3 pixel blocks. Gulve and Joshi [7] used five pair differencing with LSB substitution to achieve higher embedding capacity.

The traditional edge detection techniques can be used to identify the edges and accordingly embedding capacity in a block can be varied. Chen et al. combined canny and fuzzy edge detectors to increase edge pixels so that hiding capacity could be increased [4]. Fuzzy logic based edge detection is proposed in [24] to increase the hiding capacity and decrease the distortion. A secret key has been used to rotate the original cover image and secret bits are embedded into the edge areas of the modified cover image using LSB matching [11]. The technique discussed in [1] recognizes edge and non-edge pixels of the cover image after removing 5 LSBs of each pixel. Chakraborty et al. proposed an adaptive steganography technique using a modified median edge detector to predict the edges [2].

Zhang and Yang proposed exploiting modification direction (EMD) steganography [28]. The main goal in it is that a group of secret bits be converted to a digit in (2^{n+1})-ary notational system, where n is the size of the pixel block. This secret digit can be hidden in the pixel block by adding ±1 to only one pixel. In this technique, the hiding capacity is not appreciable. Kim advanced the EMD technique using basis vector, and $(2^{n+x}-1)$-ary notational system, where n and x are user defined values [9]. Shen and Huang made the hiding capacity of a block adaptive by using PVD with EMD to achieve higher hiding capacity and better PSNR [18]. Nguyen et al. used multiple bit planes and pixel block complexity measure to perform adaptive embedding, wherein more number of bits are hidden in high textured regions as compared to low textured regions [13].

Darabkh et al. [6] proposed an improved LSB substitution technique based on geometric equations to achieve higher security. LSB substitution has been combined with PVD in [23] to improve upon the security and hiding capacity. Furthermore, LSB substitution, PVD, and EMD have been combined together in the embedding procedure to optimize the performance [16]. Sahu and Swain [17] proposed a PVD technique using 1×5 pixel blocks, wherein one of the five pixels is paired with other four pixels to compute four difference values. Based on these difference values and improved embedding logic, the embedding performance is improved. New kinds of techniques known as quotient value differencing (QVD) [21] and PVD with overlapped pixel blocks [20] have been proposed in recent literature.

This paper proposes a mixture of MFPVD and LSB substitution using 2×3 size non-disjoint pixel blocks. The main focus of this proposed technique is to address two problems, (i) PDH analysis, and (ii) mismatch of the pixel difference range at sender and receiver. Further, it is also justified that the proposed technique achieves higher hiding capacity as compared to the existing techniques without compromising the PSNR.

2. Related Work

2.1. Wang et al.'s MFPVD Technique [26]

Wang et al. [26] proposed a MFPVD technique using 1×2 pixel blocks. The embedding and extraction procedures of Wang et al.'s technique are described in this section. The image is scanned in raster-scan order and divided into 1×2 non-disjoint blocks. Suppose (P_x, P_y) is such a block. The following steps are used for embedding data in this block.

Step 1: Calculate the difference value, $d= |P_x - P_y|$. This d value belongs to one of the six ranges in Table 1. The hiding capacity of this range is t.

Step 2: Take t bits of data, convert to decimal value, t'. Calculate the remainder value, $F = (P_x+P_y) \bmod 2^t$.

Step 3: Calculate $m=|F- t'|$ and $m_1= (2^t - m)$. Then the decimal value t' is embedded in the block (P_x, P_y) and the stego-pixel block is calculated using Equation (1) or Equation (2). If $P_x \geq P_y$, then Equation (1) is applicable, otherwise Equation (2) is applicable.

$$(P'_x,\ P'_y) = \begin{cases} \left(P_x - \left\lceil \frac{m}{2} \right\rceil,\ P_y - \left\lfloor \frac{m}{2} \right\rfloor\right), & \text{if } F > t' \text{ and } m \leq 2^{t-1} \\ \left(P_x + \left\lfloor \frac{m_1}{2} \right\rfloor,\ P_y + \left\lceil \frac{m_1}{2} \right\rceil\right), & \text{if } F > t' \text{ and } m > 2^{t-1} \\ \left(P_x + \left\lceil \frac{m}{2} \right\rceil,\ P_y + \left\lfloor \frac{m}{2} \right\rfloor\right), & \text{if } F \leq t' \text{ and } m \leq 2^{t-1} \\ \left(P_x - \left\lfloor \frac{m_1}{2} \right\rfloor,\ P_y - \left\lceil \frac{m_1}{2} \right\rceil\right), & \text{if } F \leq t' \text{ and } m > 2^{t-1} \end{cases}, \quad (1)$$

$$(P'_x,\ P'_y) = \begin{cases} \left(P_x - \left\lfloor \frac{m}{2} \right\rfloor,\ P_y - \left\lceil \frac{m}{2} \right\rceil\right), & \text{if } F > t' \text{ and } m \leq 2^{t-1} \\ \left(P_x + \left\lceil \frac{m_1}{2} \right\rceil,\ P_y + \left\lfloor \frac{m_1}{2} \right\rfloor\right), & \text{if } F > t' \text{ and } m > 2^{t-1} \\ \left(P_x + \left\lfloor \frac{m}{2} \right\rfloor,\ P_y + \left\lceil \frac{m}{2} \right\rceil\right), & \text{if } F \leq t' \text{ and } m \leq 2^{t-1} \\ \left(P_x - \left\lceil \frac{m_1}{2} \right\rceil,\ P_y - \left\lfloor \frac{m_1}{2} \right\rfloor\right), & \text{if } F \leq t' \text{ and } m > 2^{t-1} \end{cases}. \quad (2)$$

Step 4: After embedding, if fall off boundary problem (FOBP) occurs, then it is addressed using Equation (3) or Equation (4). If $|P'_x - P'_y| > 128$, then Equation (3) is applicable, otherwise Equation (4) is applicable.

$$(P'_x,\ P'_y) = \begin{cases} (0,\ P'_x + P'_y), & \text{if } P'_x < 0 \\ (P'_x + P'_y,\ 0), & \text{if } P'_y < 0 \\ (255,\ P'_x + P'_y - 255), & \text{if } P'_x > 255 \\ (P'_x + P'_y - 255,\ 255), & \text{if } P'_y > 255 \end{cases}, \quad (3)$$

$$(P'_x,\ P'_y) = \begin{cases} (P'_x + 2^{t-1},\ P'_y), & \text{if } P'_x < 0 \\ (P'_x,\ P'_y + 2^{t-1}), & \text{if } P'_y < 0 \\ (P'_x - 2^{t-1},\ P'_y), & \text{if } P'_x > 255 \\ (P'_x,\ P'_y - 2^{t-1}), & \text{if } P'_y > 255 \end{cases}. \quad (4)$$

The extraction of data from the stego-image is performed in the following manner. The stego-image is scanned in raster-scan order and divided into 1×2 non-disjoint blocks. Suppose (P'_x, P'_y) is such a block. The difference value, $d = |P'_x - P'_y|$ is calculated. This d value belongs to a range in Table 1, whose hiding capacity is t. The decimal value hidden in this block is t'. It is calculated as $t'=(P'_x+P'_y) \bmod 2^t$. Then t' is converted to t binary bits. This is the extracted binary data.

2.2. Improvement of Wang et al.'s [26] MFPVD Technique

Although Wang et al.'s MFPVD technique gives acceptable PSNR and hiding capacity, but in certain cases the extraction cannot be done properly due to the range mismatch. It can be understood by the following discussion. Let us consider a block $(P_x, P_y) = (83, 51)$.

Embedding procedure: Calculate the difference value, $d = |P_x- P_y|= |83-51| =32$. This d value belongs to the range [32, 63] of the Table 1. Thus the hiding capacity is 5. Now take 5 bits of secret binary data to be hidden in this block. Assume that it is 01101_2. Thus the decimal value of this five bits is 13, that means $t'=13$.

Calculate $F=(P_x + P_y) \bmod 2^t = (83+51) \bmod 32 = 6$.

Calculate $m= |F - t'|=|6 - 13| =7$.

Calculate $m_1=(2^t - m)= 32 - 7 = 25$.

In this case $P_x \geq P_y$, so Equation (1) should be referred. Condition (3) of Equation (1) i.e. $F \leq t$ and $m \leq 2^{t-1}$ is satisfied. So, the stego-block is

$$(P'_x,\ P'_y) = \left(P_x + \left\lceil \frac{m}{2} \right\rceil,\ P_y + \left\lfloor \frac{m}{2} \right\rfloor\right) = (86,\ 55).$$

Extraction procedure: The stego-pixel block, $(P'_x, P'_y) = (86, 55)$, $d= |P'_x - P'_y|= |86 - 55|=31$. This difference value, d belongs to the range [16, 31] of Table 1.

Table 1
The Range table in Wang et al.'s MF PVD technique [26]

Range	[0, 7]	[8,15]	[16,31]	[32,63]	[64, 127]	[128, 255]
Capacity, t	3	3	4	5	6	7

The hiding capacity as per this range is 4, i.e. t = 4. Thus 4 bits are to be extracted, but actually 5 bits are hidden. Thus this problem is known as embedding and extraction range mismatch.

To address this problem a MFPVD with LSB substitution using 2×3 pixel blocks have been proposed in this paper.

3. Proposed 2×3 Pixel Block MFPVD with LSB Substitution

The image is scanned in raster-scan order and divided into 2×3 non-disjoint blocks. For example Figure 1(a) is such a block. The pixel P_x is the central pixel. P_1, P_2, P_3, P_4 and P_5 are its left, right, bottom-left, bottom, and bottom-right neighboring pixels respectively. The embedding in a block is performed by the following steps.

Step 1: From the pixel block, the quotient block i.e. higher bit-plane block is formed by applying quotient division on every pixel using Equation (5), this block is shown in Figure 1(b). Similarly, the remainder block i.e. lower bit-plane block is formed by applying remainder division on every pixel using Equation (6), this block is shown in Figure 1(c).

$$Q_x = P_x \text{ div } 4,\ Q_i = P_i \text{ div } 4, \text{ for i= 1to 5,} \tag{5}$$

$$R_x = P_x \bmod 4,\ R_i = P_i \bmod 4, \text{ for i= 1to 5.} \tag{6}$$

Here *div* and *mod* are the quotient and remainder division functions respectively.

Step 2: Calculate the average quotient value difference d using Equation (7):

$$d = \left\lfloor \frac{1}{5} \sum_{i=1}^{5} \left(\left| Q_x - Q_i \right| \right) \right\rfloor . \tag{7}$$

Step 3: This difference value d belongs to a range R_i in Table 2. The hiding capacity of this range is t. If t value is 2, then the stego-value of R_x i.e. R'_x is set to 0. If t value is 3 then R'_x is set to 1. Similarly, if t value is 4, then R'_x is set to 2. This R'_x value is the indicator for using t value while hiding data in quotients of this block and will be used at the time of extraction. For i=1 to 5, take two binary bits from binary data stream, convert to decimal value, it is the stego-value R'_i for R_i.

Table 2
The range table of the proposed technique

Range, R_i	[0,15]	[16,31]	[32,63]
Capacity, t	2	3	4

Step 4: Calculate the remainder, F_i using Equation (8):

$$F_i = \left(Q_x + Q_i\right) \bmod 2^t \text{ , for i= 1 to 5.} \tag{8}$$

For i=1 to 5, take t bits of data and convert it to decimal value t'_i. Calculate $m_i = |F_i - t'_i|$ and $n_i = 2^t - m_i$.

Step 5: For i = 1 to 5, after hiding t bits in quotient Q_i, the stego-quotient Q'_i, is calculated using Equations (9):

$$Q'_i = \begin{cases} (Q_i - m_i)\ , & \text{if } (F_i > t'_i) \text{ and } (m_i \le 2^{t-1}) \\ (Q_i + n_i)\ , & \text{if } (F_i > t'_i) \text{ and } (m_i > 2^{t-1}) \\ (Q_i + m_i)\ , & \text{if } (F_i \le t'_i) \text{ and } (m_i \le 2^{t-1}) \\ (Q_i - n_i)\ , & \text{if } (F_i \le t'_i) \text{ and } (m_i > 2^{t-1}) \end{cases} . \tag{9}$$

Step 6: Now the fall off boundary problem (FOBP) is to be addressed. If any of these stego-quotients, Q'_i is less than 0 or greater than 63, then FOBP arises. It is addressed using Equation (10):

$$Q'_i = \begin{cases} (Q'_i + 2^t)\ , & \text{if } Q'_i < 0 \\ (Q'_i - 2^t)\ , & \text{if } Q'_i > 63 \end{cases} , \quad \text{for i=1 to 5.} \tag{10}$$

Step 7: The stego-pixel values are calculated by Equation (11) and the stego-pixel block is as shown in Figure 1(d):

$$P'_x = Q'_x \times 4 + R'_x,\ P'_i = Q'_i \times 4 + R'_i \text{, for i=1 to 5.} \tag{11}$$

Figure 1
(a) Original block, (b) Quotient block, (c) Remainder and (d) Stego-pixel block

P_1	P_x	P_2
P_3	P_4	P_5

a

Q_1	Q_x	Q_2
Q_3	Q_4	Q_5

b

R_1	R_x	R_2
R_3	R_4	R_5

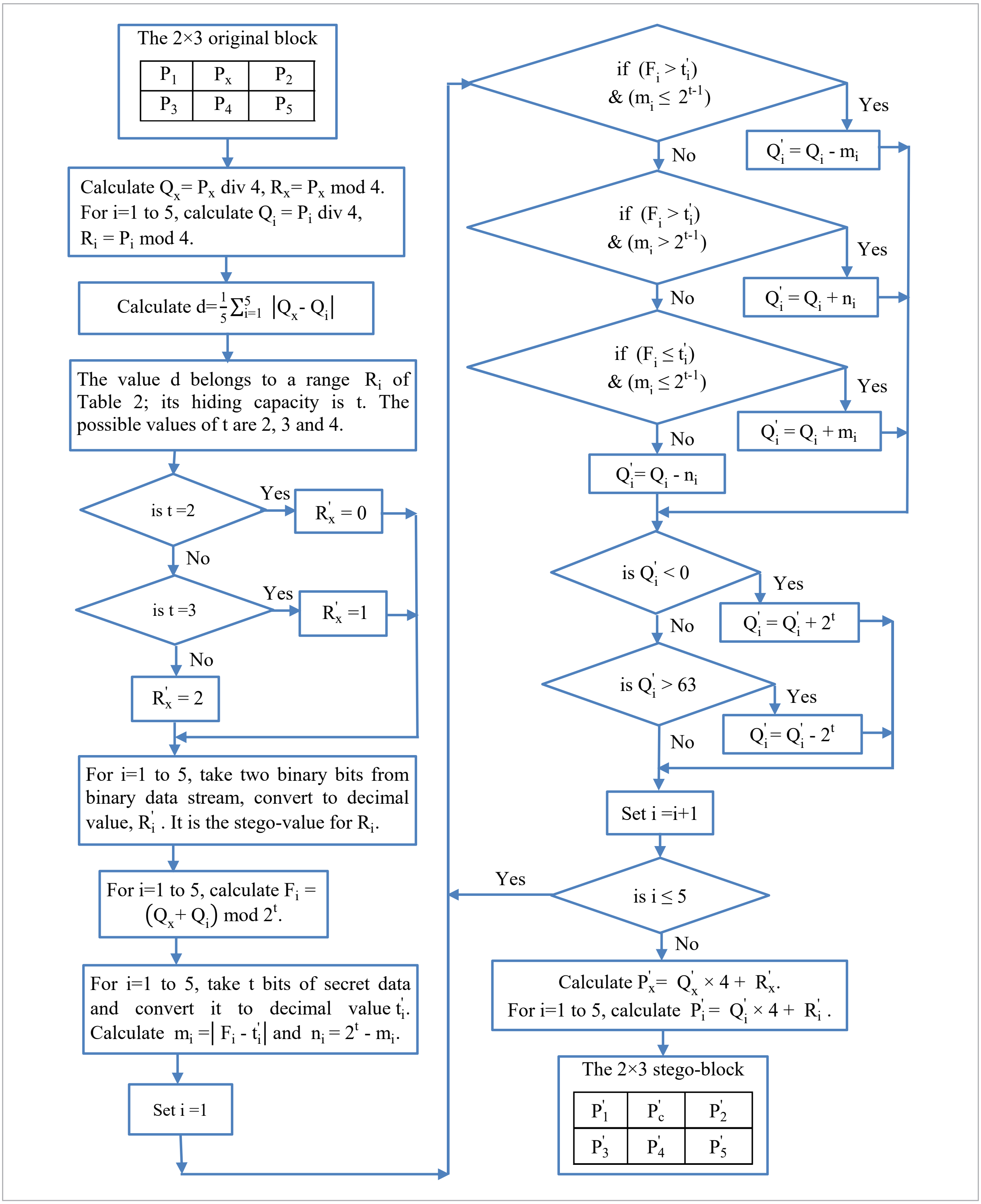
c

P'_1	P'_x	P'_2
P'_3	P'_4	P'_5

d

Figure 2

The flowchart for the embedding procedure of the proposed MFPVD+LSB technique



The **extraction** of hidden data is very simple. The stego-image is scanned in raster-scan order and divided into 2×3 non-disjoint blocks. For example Figure 1(d) is such a block. The pixel P_x' is the central pixel. P_1', P_2', P_3', P_4' and P_5' are its neighboring pixels. The extraction is performed by the following steps.

Step 1: From this stego-pixel block, the decimal equivalent of six most significant bits (MSBs) of each pixel is calculated by applying quotient division as in Equation (12). Similarly, the decimal equivalent of two LSBs of every pixel is calculated by remainder division as in Equation (13):

$$Q_x' = P_x' \text{ div } 4,\ \ Q_i' = P_i' \text{ div } 4,\quad \text{for } i = 1 \text{ to } 5, \tag{12}$$

$$R_x' = P_x' \bmod 4,\ \ R_i' = P_i' \bmod 4,\quad \text{for } i = 1 \text{ to } 5. \tag{13}$$

Step 2: If R_x' value is 0, then set t=2. If R_x' value is 1, then set t=3. If R_x' value is 2, then set t=4.

Step 3: For i=1 to 5, each of the remainders, R_i' is converted to two binary bits and added to extracted bit stream.

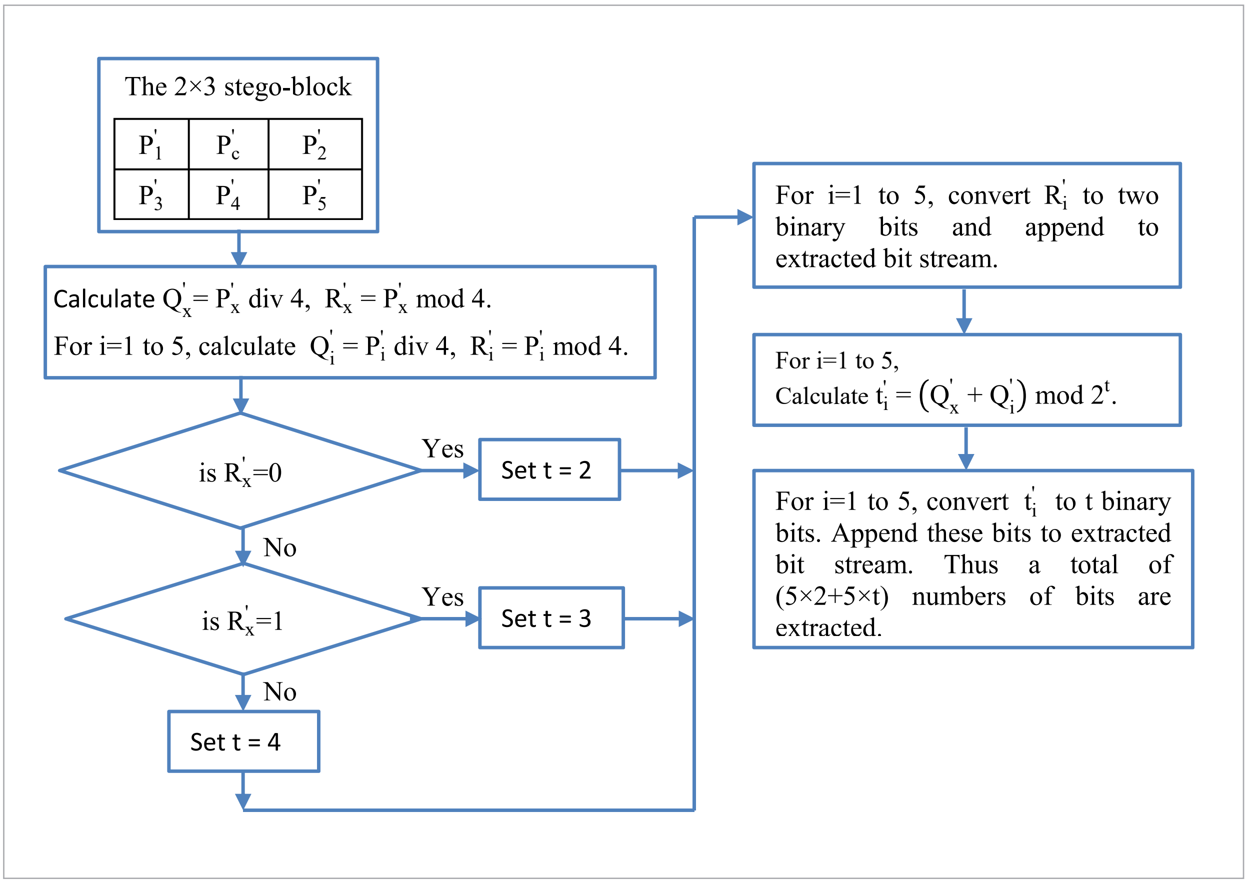
Step 4: For i=1 to 5, calculate t_i' using Equation (14):

$$t_i' = \left(Q_x' + Q_i'\right) \bmod 2^t. \tag{14}$$

Step 5: For i=1 to 5, convert each t_i' value to t binary bits. Add these bits to the extracted bit stream. Thus a total of (5×2+5×t) numbers of bits are extracted.

To facilitate the readers for a quick understanding of the embedding and extraction procedures, the flowcharts for embedding and extraction procedures are given in Figures 2 and 3, respectively.

Figure 3
The flowchart for the extraction procedure of the proposed MFPVD+LSB technique



4. An Example of Embedding and Extraction Procedures

Embedding procedure: Let us apply the embedding procedure on a block shown in Figure 4(a). The pixel values are, $P_x = 46$, $P_1 = 45$, $P_2 = 47$, $P_3 = 100$, $P_4 = 101$, $P_5 = 102$.

Figure 4

Example of (a) original, (b) quotient, (c) remainder, and (d) stego blocks

a

45	46	47
100	101	102

b

11	11	11
25	25	25

c

1	2	3
0	1	2

d

26	46	61
118	93	88

Step 1: From the original block the quotient block is formed using Equation (5) and it is shown in Figure 4(b). $Q_x = 46$ div 4 =11, Q_1= 45 div 4 =11, Q_2= 47 div 4 =11, Q_3= 100 div 4 =25, Q_4= 101 div 4 =25, and Q_5= 102 div 4 =25. Similarly the remainder block is formed using Equation (6) and it is shown in Figure 4(c). R_x= 46 mod 4 = 2, R_1= 45 mod 4 = 1, R_2 = 47 mod 4 = 3, R_3 = 100 mod 4 = 0, R_4 = 101 mod 4 =1, and R_5 =102 mod 4 =2.

Step 2: An average quotient value difference, d is calculated using Equation (7).

$$d = \left\lceil \frac{1}{5}\{|46-45|+|46-47|+|46-100|+|46-101|+|46-102|\} \right\rceil = \; = \left\lceil \frac{167}{5} \right\rceil = \lceil 33.4 \rceil = 34.$$

Step 3: This d value belongs to the range [32, 63], so t = 4, then R_x' value is set to 2. Suppose the binary data to be hidden is $10\ 01\ 10\ 01\ 00\ 0001\ 1010\ 1000\ 0010\ 0001_2$. For i=1 to 5, take 2 bits of data and get R_i' value. Hence, $R_1' = 2$, $R_2' = 1$, $R_3' = 2$, $R_4' = 1$, and $R_5' = 0$.

Step 4: Using Equation (8), $F_1 = (Q_x + Q_1) \bmod 2^1 = (11+11) \bmod 2^4 = 6$. Similarly, $F_2 = 6$, $F_3 = 4$, and $F_5 = 4$.

Take next 4 bits of data from secret data stream, this is 0001_2 and convert it to decimal value, it is 1. Thus t_1 is 1. Calculate $m_1=|F_1-t_1'| = |6-1|=5$, and $n_1=2^4-m_1= (16-5) = 11$. Similarly, $t_2' =10$, $m_2=4$, $n_2= 12$, $t_3' = 8$, $m_3=4$, $n_3= 12$, $t_4' = 2$, $m_4=2$, $n_4= 14$, $t_5'=1$, $m_5=3$, and $n_5= 13$.

Step 5: Using Equation (9) it can be found that, $(F_1 > t_1')$ and $(m_1 \leq 2^{t-1})$ satisfies. Thus $Q_1'=(Q_1-m_1) = 6$. Similarly, $Q_2' = 15$, $Q_3' = 29$, $Q_4' = 23$, and $Q_5'= 22$.

Step 6: All these stego-values Q_1', Q_2', Q_3', Q_4', and Q_5' lies in between 0 and 63, hence FOBP does not occur. Thus Equation (10) is not applicable.

Step 7: The stego-values of the pixels are calculated by Equation (11), $P_x' = Q_x' \times 4 + R_x' = 11 \times 4 + 2 = 46$. Similarly, $P_1'= 26$, $P_2'= 61$, $P_3' = 118$, $P_4' = 93$, and $P_5' = 88$. The stego-pixel block is shown in Figure 4(d).

Extraction procedure: Now let us apply the extraction procedure to the block shown in Figure 4(d). The pixel $P_x' = 46$, $P_1' = 26$, $P_2' = 61$, $P_3' = 118$, $P_4' = 93$, and $P_5' = 88$.

Step 1: From these stego-pixels, the quotients and remainders are calculated using Equations (12) and (13) respectively. So, $Q_x'=11$, $Q_1' = 6$, $Q_2'= 15$, $Q_3'= 29$, $Q_4'= 23$, $Q_5'= 22$, $R_x' = 2$, $R_1'= 2$, $R_2'= 1$, $R_3' = 2$, $R_4' = 1$, and $R_5'= 0$.

Step 2: R_x' value is 2, so t=4.

Step 3: For i = 1 to 5, R_i' value is converted to 2 binary bits, that means each of the values 2, 1, 2, 1, 0 are converted to 2 binary bits. Hence the extracted bits from remainders are $10\ 01\ 10\ 01\ 00_2$.

Step 4: Using Equation (14), $t_1'=(Q_x'+Q_1') \bmod 2^1 = (11+6) \bmod 2^4 = 1$. Similarly, $t_2' = 10$, $t_3' = 8$, $t_4' = 2$, and $t_5' = 1$.

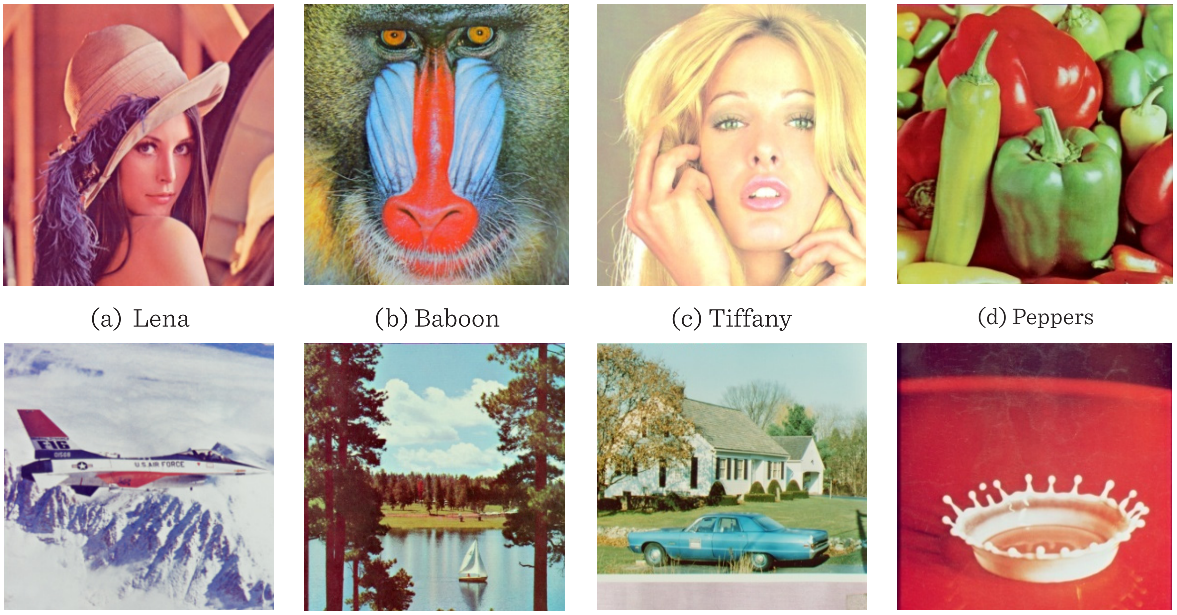
Step 5: For i = 1 to 5, convert t_i' value to t binary bits. That means convert each of the values 1, 10, 8, 2, and 1 into 4 binary bits. Thus the extracted bits from the quotients are $0001\ 1010\ 1000\ 0010\ 0001_2$.

From remainders and quotients all the bits extracted are $10\ 01\ 10\ 01\ 00\ 0001\ 1010\ 1000\ 0010\ 0001_2$. These bits are same as the embedded bits.

5. Results and Discussion

MATLAB is used to simulate the proposed MFP-VD+LSB substitution technique. The RGB images collected from SIPI image data base [25] are used for testing the technique. The images are of size 512×512. Each pixel is 3 bytes, so the total size of a test image is 512×512×3 bytes. Each byte is considered as a single unit of calculation. Testing is performed with a large number of images. Eight original test images are shown in Figure 5. Their respective stego-images are shown in Figure 6. Eight lakhs and forty thousand

Figure 5
Original images (size 512×512×3 bytes)



(a) Lena (b) Baboon (c) Tiffany (d) Peppers
(e) Jet (f) Boat (g) House (h) Pot

Figure 6
Stego-images of proposed MFPVD+LSB substitution technique. In each of these images, eight lakhs and forty thousand (840,000) bits of data has been hidden.

PSNR = 39.52 PSNR = 39.28 PSNR = 38.62 PSNR = 39.19
PSNR = 39.53 PSNR = 39.37 PSNR = 39.47 PSNR = 39.37

(840,000) bits of data has been hidden in each of these stego-images. No observable marks are identified from these stego-images.

The proposed MFPVD+LSB substitution technique is compared with the existing techniques in [26] and [22]. The comparison is performed in terms of PSNR, hiding capacity, quality index (Q) and bit rate i.e. bits per byte (BPB) [14]. PSNR is a measure of distortion in stego-image. Lesser distortion means higher PSNR and vice versa. It is based on mean square error (MSE). Equations (15) and (16) are used to measure the MSE and PSNR respectively. In Equation (15), p_{ij} and q_{ij} are the pixel values of the original and stego-images respectively. The m and n are the number of rows and number of columns in the image respectively.

$$MSE = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} \left(p_{ij} - q_{ij}\right)^2, \tag{15}$$

$$PSNR = 10 \times \log_{10} \frac{255 \times 255}{MSE}. \tag{16}$$

The hiding capacity refers to the maximum number of bits that can be hidden in the image. It is sometimes represented as BPB i.e. the average number of bits that can be hidden per a byte of the image. The Q is a measure of equivalence between original image and stego-image. It is calculated using Equation (17):

$$Q = \frac{4 \sigma_{xy} \bar{p} \bar{q}}{\left(\sigma_x^2 + \sigma_y^2\right)\left(\bar{p}^2 + \bar{q}^2\right)}. \tag{17}$$

In Equation (17), $\bar{p}$ and $\bar{q}$ are the mean pixel values of the original and stego-images respectively. The σ_x^2 and σ_y^2 are the standard deviation for the original and stego-images respectively. The term σ_{xy} is the covariance. These are computed by Equations (18)-(22):

$$\bar{p} = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij}, \tag{18}$$

$$\bar{q} = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} q_{ij}, \tag{19}$$

$$\sigma_x^2 = \frac{1}{m \times n - 1} \sum_{i=1}^{m} \sum_{j=1}^{n} \left(p_{ij} - \bar{p}\right)^2, \tag{20}$$

$$\sigma_y^2 = \frac{1}{m \times n - 1} \sum_{i=1}^{m} \sum_{j=1}^{n} \left(q_{ij} - \bar{q}\right)^2, \tag{21}$$

$$\sigma_{xy} = \frac{1}{m \times n - 1} \sum_{i=1}^{m} \sum_{j=1}^{n} \left(p_{ij} - \bar{p}\right)\left(q_{ij} - \bar{q}\right). \tag{22}$$

Tables 3 and 4 record the results of the existing and proposed techniques. The BPB of the proposed technique is 3.34. It can be observed that, without compromising the PSNR, the hiding capacity and BPB of the proposed technique is higher than that of the existing techniques. For the proposed technique, the improved capacity is not only the admiring factor, but also the correctness of data extraction unlike Wang et al.'s [26] technique. The extraction is correctly done by inserting the indicator bits in the central pixel of the block during embedding, which is referred during extraction.

The proposed MFPVD+LSB substitution technique is analyzed by PDH analysis. The PDH analysis is performed by calculating the difference value between every pair of pixels [14]. A pair comprises of two consecutive pixels. These difference values will be from -255 to +255 including 0. The frequency of each of these difference values is calculated. A graph is plotted, with the pixel difference value on X-axis and frequency on Y-axis. The graph obtained is called as the PDH. The PDH of original image will be a smooth curve. If the PDH of the stego-image is also a smooth curve then steganography is not detected. If the PDH of stego-image shows step effects, then steganography is detected. Figure 7 represents the PDH analysis on Lena, Baboon, Tiffany, Peppers, Jet, Boat, House, and Pot images for the proposed MFPVD+LSB substitution technique. There are eight sub-figures in total. Each sub-figure represents two curves. The solid line curve is for the original image and the dotted line curve is for the stego-image. The curve of original image will be smooth in nature means free from zig-zag appearance. This zig-zag appearance is called as step effect. In all the eight cases, the PDH curves of stego-images do not show any step effects. Hence it can be concluded that the proposed technique is tolerant to PDH analysis.

The RS analysis performs some statistical calculation in the following way [14]. Define a function, F_1: $2n \leftrightarrow 2n+1$. It defines two transformations, (i) from value 2n to value 2n + 1, and (ii) from value 2n + 1 to value 2n. Similarly, define another function F_{-1}: $2n \leftrightarrow 2n-1$. It defines other two transformations, (i) from

Table 3

The results of the existing technique [22]

Images 512×512×3	Swain's 2×3 PVD with MLSB substitution				Swain's 3×3 PVD with MLSB substitution			
	PSNR	Capacity	Q	BPB	PSNR	Capacity	Q	BPB
Lena	41.14	2379222	0.999	3.03	41.04	2371255	0.999	3.02
Baboon	34.35	2496404	0.996	3.17	33.76	2502616	0.996	3.18
Tiffany	37.27	2376135	0.996	3.02	37.2	2366437	0.996	3.01
Peppers	35.56	2379292	0.998	3.03	35.15	2371837	0.998	3.02
Jet	39.57	2384676	0.998	3.03	39.52	2377031	0.998	3.02
Boat	35.84	2409235	0.998	3.06	35.32	2405009	0.998	3.06
House	36.9	2404582	0.998	3.06	37.58	2399229	0.998	3.05
Pot	40.35	2369274	0.999	3.01	40.34	2359271	0.999	3
Average	37.62	2399853	0.998	3.05	37.49	2394086	0.998	3.04

Table 4

The Results of Wang et al.'s MFPVD [26] and proposed MFPVD+LSB technique

Images 512×512×3	Wang et al.'s 1×2 MFPVD				Proposed 2×3 MFPVD+LSB substitution			
	PSNR	Capacity	Q	BPB	PSNR	Capacity	Q	BPB
Lena	38.09	2470171	0.998	3.14	39.52	2622545	0.999	3.33
Baboon	40.37	2811651	0.999	3.57	39.28	2635620	0.9988	3.35
Tiffany	37.23	2444837	0.996	3.11	38.62	2624980	0.9975	3.34
Peppers	38.74	2470673	0.999	3.14	39.19	2625140	0.9991	3.34
Jet	36.73	2446005	0.996	3.11	39.53	2625185	0.9981	3.34
Boat	41.98	2575764	0.999	3.27	39.37	2626535	0.9992	3.34
House	37.68	2524705	0.998	3.21	39.47	2625075	0.9988	3.34
Pot	41.39	2398616	0.999	3.05	39.37	2623855	0.9993	3.34
Average	39.03	2517803	0.998	3.2	39.29	2626117	0.9987	3.34

value 2n to value 2n – 1, and (ii) from value 2n - 1 to value 2n. The image, say M is divided into a number of equal size blocks. Suppose such a block is G whose pixels are X_1, X_2, X_3, ..., X_n. Then use the function f= $\sum_{i=1}^{n-1}|X_{i+1}-X_i|$ to measure the smoothness of G. Then apply F_1 to all the blocks of M and define the two parameters R_m and S_m as in Equations (23) and (24) respectively. Similarly, apply F_{-1} to all the blocks of M and define the two parameters R_{-m} and S_{-m} as in Equations (25) and (26) respectively.

$$R_m = \frac{\text{Number of blocks satisfying } f(F_1(G)) > f(G)}{\text{Total number of blocks}}, \quad (23)$$

$$S_m = \frac{\text{Number of blocks satisfying } f(F_1(G)) < f(G)}{\text{Total number of blocks}}, \quad (24)$$

$$R_{-m} = \frac{\text{Number of blocks satisfying } f(F_{-1}(G)) > f(G)}{\text{Total number of blocks}}, \quad (25)$$

$$S_{-m} = \frac{\text{Number of blocks satisfying } f(F_{-1}(G)) < f(G)}{\text{Total number of blocks}}. \quad (26)$$

Figure 7

PDH analysis of the proposed 2×3 MFPVD+LSB substitution technique, (a) Lena, (b) Baboon, (c) Tiffany, (d) Peppers, (e) Jet, (f) Boat, (g) House, and (h) Pot images. In all the eight sub-figures, the solid line curve is for the original image, and the dotted line curve is for the stego-image

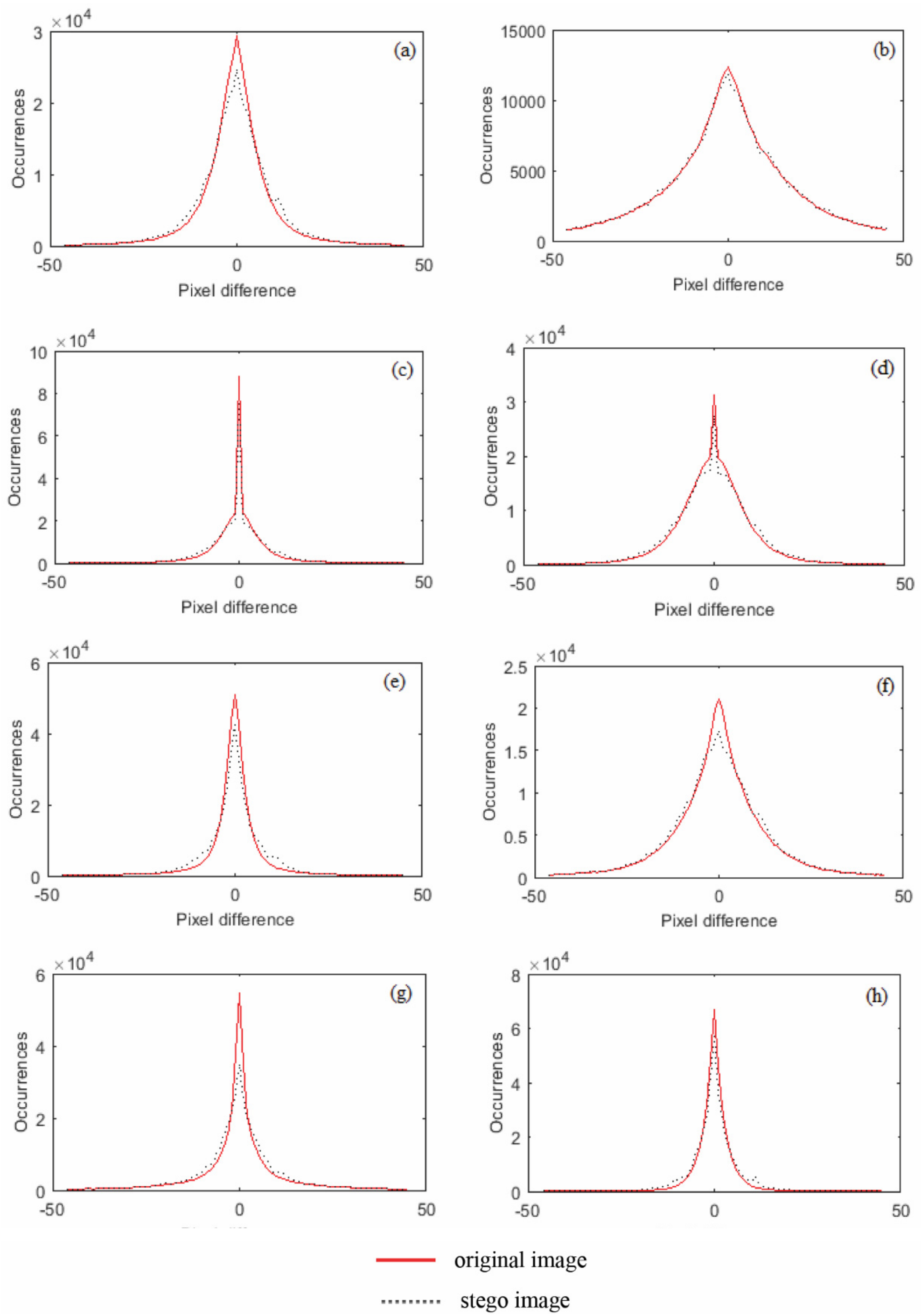
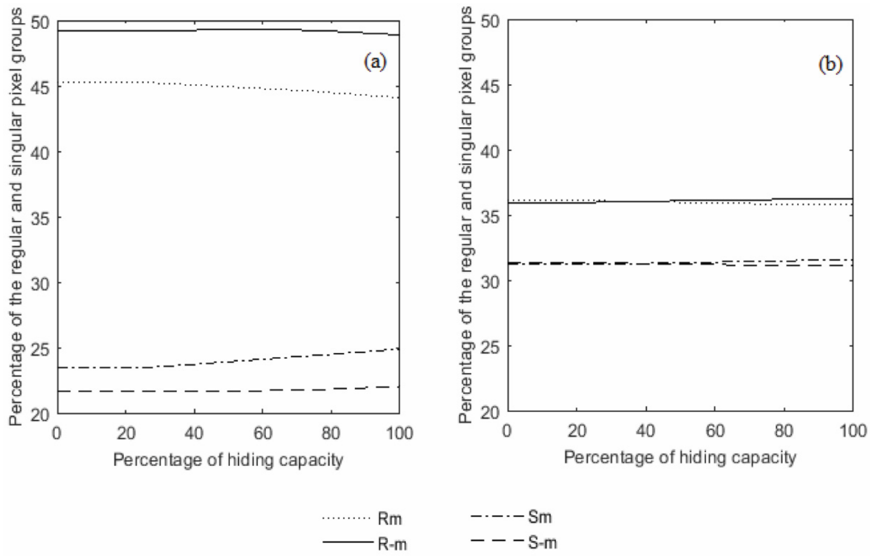


Figure 8

RS analysis of the proposed 2×3 MFPVD+LSB substitution technique, (a) Tiffany, and (b) Baboon images. In both the sub-figures, the lines for R_m and R_{-m} are close to each other. Similarly the lines for S_m and S_{-m} are close to each other. Furthermore, the condition $R_m \approx R_{-m} > S_m \approx S_{-m}$ also satisfies



RS analysis is performed by using these four parameters. If the condition $R_m \approx R_{-m} > S_m \approx S_{-m}$ is true, then RS analysis fails to detect the steganography technique. If the condition $R_{-m} - S_{-m} > R_m - S_m$ is true, then the RS analysis succeeds in detecting the steganography technique.

The RS analysis of the proposed technique on Tiffany and Baboon images are shown in Figure 8. Tiffany is a smooth image and Baboon is an edge image. It can be observed from Figure 8 that for the proposed technique the condition $R_m \approx R_{-m} > S_m \approx S_{-m}$ satisfies for the edge image, Baboon. It also satisfies for smooth image, Tiffany. As Tiffany is the smooth image and Baboon is the edge image, it can be predicted that the results of all the remaining images will fall in between these two images. Thus based on the observations of these two images, it can be concluded that the proposed technique escapes from RS analysis.

6. Conclusion

This paper proposes a new steganography technique known as MFPVD+LSB substitution. It uses 2×3 size pixel blocks to utilize the edges in five directions. From the pixel block, the quotient and remainder blocks are derived. One of the quotients is termed as central quotient. Considering the central quotient and its five neighboring quotients, five difference values are calculated. Based on the average of all the quotient value differences, the hiding capacity in all the five directions is decided. The central remainder acts as an indicator to extract the number of bits from the five quotients at the time of extraction. Each of the remaining remainders hides two bits of data using LSB substitution. The embedding equations are designed in such a way that the central pixel will not change while embedding the data. The experiments are performed with images from SIPI image data base. The experimental results reveal that the proposed technique does not show any step effect, so it is not vulnerable to PDH analysis. It is also observed that without compromising the PSNR the recorded hiding capacity values are greater than that of the related existing techniques. Furthermore, it is proved that the proposed MFPVD+LSB substitution technique is undetectable by RS analysis.

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