Performance Analysis of LSB-based Data Hiding Techniques

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Abstract: In data hiding methods, least significant bits replacement has been used broadly by combining with other embedding techniques. In this study, performance and comparison of data hiding techniques based on least significant bits modification are analyzed. In experimental results, visual image quality of each pixel layer is tested to show the effect on the embedding layer in each pixel. The embedding capacity and histogram analysis are compared with previous works.

Key-Words: data hiding, steganography, least significant bit, information hiding, steganalysis.

1 Introduction

Data security is very important issue to prevent from unauthorized access as Internet has been spread over. Data hiding techniques can be one of solutions to provide the ownership and copyright protection. In data hiding techniques, least significant bit (LSB) replacement is a basic technique that can embed the secret data into right position (least significant bit) of a pixel within a permitted limit on image distortion to human visual system [1-3]. There are many kinds of algorithm which is based on LSB replacement techniques [4-11].

In this study, *k*-bit LSB replacement, LSB matching revisited and XOR-based data hiding methods are described. Next, performance analysis and comparison of data hiding methods based on least significant bits modification are comparative. In especial, histogram of stego-image is compared with previous works that have 1 bit per pixel, 2 bits per pixel and variable embedding capacity.

2 Literature Discussions

In this section, some previous works with 1 bit per pixel (1 bpp) on the embedding capacity are described. A gray cover image with W x H can be displayed as Fig 1.

A pixel value $p(x,y)$ has a range from 0 to 255 for a gray image as Eq. (1).

$$p(x,y) = \{p(x,y) \mid 0 \le p(x,y) \le 255, 0 \le x \le W, 0 \le y \le H\} \quad (1)$$

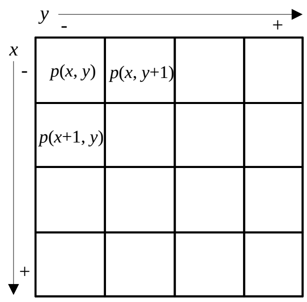


Fig. 1. Structure of a cover image.

2.1 *k*-bit LSB Replacement

In general, the k secret bits can be embedded into the k-rightmost positions in the pixel of a cover image for k-bit LSB replacement technique.

Assume that s_i are secret bit stream for a pixel value $p(x,y)$, a new pixel $p'(x,y)$ can be calculated by Eq. (2) in embedding process.

$$p'(x,y) = \left(p(x,y) - (p(x,y) \bmod 2^k) + \sum_{i=0}^{k-1} s_i \right) \quad (2)$$

In extracting process, the secret bits can be extracted directly from stego-pixel without any extra information.

$$s_i = p'(x,y) \bmod 2^k \quad (3)$$

When $k = 1$ is given, it is called 1-bit LSB replacement technique.

2.2 LSB Matching Revisited

LSB matching revisited [7] was proposed to improve the image quality with the same embedding capacity. The proposed method modified the LSB matching [6] to ± 1 from the pixel-pair values of a cover image. The function $\mathrm{F(i,j)}$ is given as Eq. (4).

$$F(i,j) = f\big(p(x,y), p(x,y+1)\big) = LSB\left(\left\lfloor \frac{p(x,y)}{2} \right\rfloor + p(x,y+1)\right) \quad (4)$$

For two secret bits $\mathrm{s_i}$ and $\mathrm{s_{i+1}}$, new two pixel values can be calculated by Eq. (5).

$$\begin{pmatrix} p'(x,y) \\ p'(x,y+1) \end{pmatrix} = \begin{cases} (p(x,y), p(x,y+1) \pm 1), \\ \quad if\ s_i = LSB\big(p(x,y)\big)\ and\ s_{i+1} \neq F(i,j) \\ \big(p(x,y), p(x,y+1)\big), \\ \quad if\ s_i = LSB\big(p(x,y)\big)\ and\ s_{i+1} = F(i,j) \\ \big(p(x,y) - 1, p(x,y+1)\big), \\ \quad if\ s_i \neq LSB\big(p(x,y)\big)\ and\ s_{i+1} = F(i-1,j) \\ \big(p(x,y) + 1, p(x,y+1)\big), \\ \quad if\ s_i \neq LSB\big(p(x,y)\big)\ and\ s_{i+1} \neq F(i-1,j) \end{cases} \quad (5)$$

2.3 XOR-based Data Hiding

The data hiding technique using XOR operation in a sub-block with three pixels was proposed to embed three secret bits [13]. For three pixels $\mathrm{p(x,y) = (a_{i+7}a_{i+6}a_{i+5}a_{i+4}a_{i+3}a_{i+2}a_{i+1}a_i)}$, $\mathrm{p(x,y+1) = (b_{i+7}b_{i+6}b_{i+5}b_{i+4}b_{i+3}b_{i+2}b_{i+1}b_i)}$, $\mathrm{p(x,y+2) = (c_{i+6}c_{i+5}c_{i+4}c_{i+3}c_{i+2}c_{i+1}c_i)}$, and three secret bits $\mathrm{s_i, s_{i+1}, s_{i+2}}$, new three pixels can be calculated as follows. First, new three functions $\mathrm{F_i, F_{i+1}, F_{i+2}}$ are obtained by Eq. (6).

$$\begin{aligned} F_i &= a_i \oplus a_{i+1} \oplus b_i \\ F_{i+1} &= b_i \oplus b_{i+1} \oplus c_i \\ F_{i+2} &= c_i \oplus c_{i+1} \oplus a_i \end{aligned} \quad (6)$$

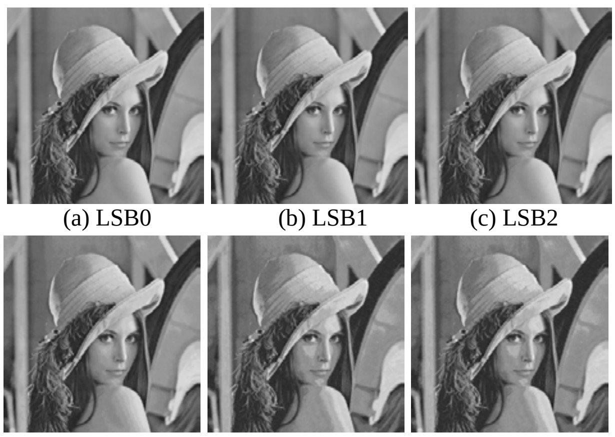
Next, new three pixels can be calculated by Eq. (7) that is simplified.

$$(p'(x,y), p'(x,y+1), p'(x,y+2)) = \begin{cases} \big(p(x,y), p(x,y+1), p(x,y+2)\big)\ \ if\ F_i = s_i\ and\ F_{i+1} = s_{i+1} and\ F_{i+2} = s_{i+2} \\ \big(p(x,y), p(x,y+1) \pm 1, p(x,y+2)\big)\ \ if\ F_i \neq s_i\ and\ F_{i+1} = s_{i+1} and\ F_{i+2} = s_{i+2} \\ (p(x,y), p(x,y+1), p(x,y+2) \pm 1)\ \ if\ F_i = s_i\ and\ F_{i+1} \neq s_{i+1} and\ F_{i+2} = s_{i+2} \\ \big(p(x,y) \pm 1, p(x,y+1), p(x,y+2)\big)\ \ if\ F_i = s_i\ and\ F_{i+1} = s_{i+1} and\ F_{i+2} \neq s_{i+2} \\ \big(p(x,y), p(x,y+1) \pm 1, p(x,y+2)\big)\ \ if\ F_i \neq s_i\ and\ F_{i+1} \neq s_{i+1} and\ F_{i+2} = s_{i+2} \\ \big(p(x,y), p(x,y+1), p(x,y+2) \pm 1\big)\ \ if\ F_i = s_i\ and\ F_{i+1} \neq s_{i+1} and\ F_{i+2} \neq s_{i+2} \\ \big(p(x,y) \pm 1, p(x,y+1), p(x,y+2)\big)\ \ if\ F_i \neq s_i\ and\ F_{i+1} = s_{i+1} and\ F_{i+2} \neq s_{i+2} \\ (p(x,y), p(x,y+1), p(x,y+2) \pm 1)\ \ if\ F_i \neq s_i\ and\ F_{i+1} \neq s_{i+1} and\ F_{i+2} \neq s_{i+2}\ \ and\ p(x,y+2)\ mod\ 2 = 0 \\ \big(p(x,y) \pm 1, p(x,y+1), p(x,y+2)\big)\ \ if\ F_i \neq s_i\ and\ F_{i+1} \neq s_{i+1} and\ F_{i+2} \neq s_{i+2}\ \ and\ p(x,y)\ mod\ 2 = 0 \end{cases} \quad (7)$$

These data hiding techniques can embed the secret bit in the pixel, in other words, the embedding capacity is 1 bit per pixels.

3 Comparative Analysis

In experimental results, 512 x 512 gray images were used as cover images and the secret data was generated by pseudo-random number. To understand the distortion of image for layer level, the results of Lena image by inserting one bit for each pixel layer are shown in Fig. 2.



(a) LSB0 (b) LSB1 (c) LSB2

(d) LSB3 (e) LSB4 (f) LSB5

(g) LSB6 (h) LSB7

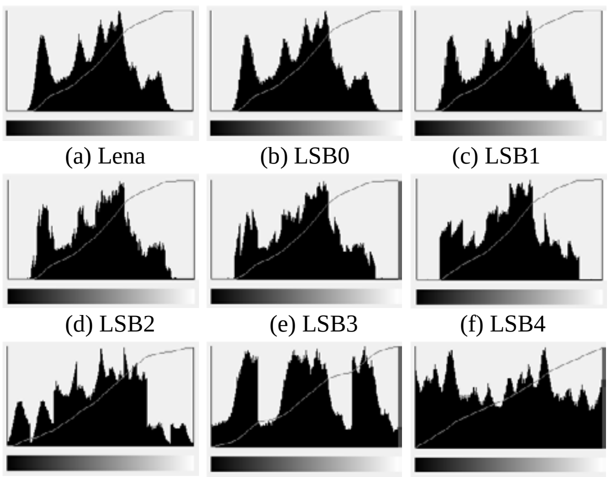
Fig. 2. Result images for layer level.

Even though the number of changed bits is similar except the different layer in 512 x 512 gray images, the value of PSNR and Q index are different as shown in Table 1.

Table 1. Comparison of visual quality

Layer	PSNR (dB)	Q index
LSB0	51.14	0.9861
LSB1	45.12	0.9500
LSB2	39.10	0.8484
LSB3	33.08	0.6770
LSB4	27.05	0.4589
LSB5	21.05	0.3054
LSB6	15.01	0.1286
LSB7	9.00	0.0019

Histogram analysis of pixel layer is tested as shown in Fig. 3. For Lena image, histogram of stego-image is different as the layer is higher. In especial, histogram graph of Fig. 3(i) corresponding to Fig. 2(i) has more distortion than any other histogram graphs.



(a) Lena (b) LSB0 (c) LSB1

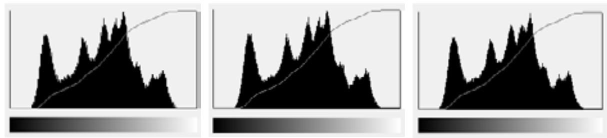
(d) LSB2 (e) LSB3 (f) LSB4

(g) LSB5 (h) LSB6 (i) LSB7

Fig. 3. Histogram analysis for layer level.

3.1 Data Hiding with 1bpp

LSB matching revisited method [7] has a 1 bpp embedding capacity. For Lena image, the *PSNR* and *Q* index are 51.14 dB and 0.9861 in the LSB matching revisited. The comparison of LSB based methods with 1 bpp embedding capacity is shown in Fig. 4.

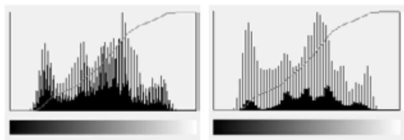


(a) 1-bit LSB (b) LSB Matching (c) LSB Matching Revisited

Fig. 4. Histogram analysis for 1 bpp methods.

3.2 Data Hiding with 2bpp

2-bit LSB replacement and 2-bit XOR embedding method [14] are compared in Fig. 5. For Lena image, the PSNR and Q index are 44.46 and 0.9508 in 2-bit XOR method.

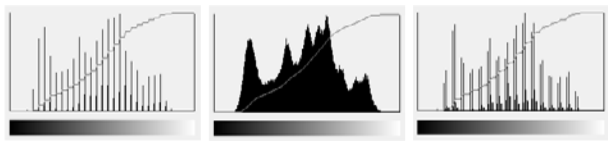


(a) 2-bit LSB (b) 2-bit XOR

Fig. 5. Histogram analysis for 2 bpp methods.

3.3 Data Hiding with 3bpp and Variable Embedding Capacity

3-bit LSB replacement and variable data hiding methods are tested. Two methods using 3 pixels sub-lock [11] and modulo three strategy [12] have 233,024 bits and 960,100 bits in embedding capacity.



(a) 3-bit LSB (b) 3 pixels sub-block (c) modulo three strategy

Fig. 6. Histogram analysis for variable embedding capacity.

4 Conclusions and Summary

In this study, data hiding methods based on least significant bits have been comparative. There were many kinds of works that had various embedding capacity. In the study, image analysis and histogram analysis for each pixel layer were performed and compared. Data hiding methods with 1 bpp embedding capacity were difficult to discriminate between the cover and stego-image. Data hiding methods with 2 bpp and above embedding capacity could not the distortion with the human visual system, but the difference could be caught out by histogram of stego-images. In the future, a novel data hiding method based on least significant bits with high visual image quality and robust to histogram attack will be worked.

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